Copyright 1943, by the AMERICAN SOCIETY OF NAVAL ENGINEERS

JOURNAL

OF THE

AMERICAN SOCIETY OF NAVAL ENGINEERS

VOL. 55. AUGUST 1943 No. 3

The Society as a body is not responsible for statements made by individual members

COUNCIL OF THE SOCIETY

(Under whose supervision this number is published).

Rear Admiral J. J. BROSHEK, U.S.N.
Rear Admiral E. L. COCHRANE, U.S.N.
Rear Admiral EARLE W. MILLS, U.S.N.
Rear Admiral C. L. BRAND, U.S.N.
Captain LISLE F. SMALL, U.S.N.
Captain J. N. HEINER, U.S.C.G.
Mr. A. F. E. HORN.
Mr. D. S. BRIERLEY.
Captain JAMES E. HAMILTON, U.S.N.

FUEL OIL PRESSURE CONTROL VALVES.

BY RAYMOND W. HITESHUE.*

With the advent of Naval superheat control boilers (integral separately fired superheaters), an accurate control of fuel oil pressures to the burner manifolds became mandatory for sensitive control of total steam temperature. Of equal importance was the close control necessary on boilers employing semi-wide range nozzles. The increased firing range possible with such nozzles, is of course, attributed solely to pressure variations. In some semi-wide range installations, the number of sprayer plate sizes required for covering the entire steaming range has been reduced approximately 40 per cent—a valuable asset to maneuverability. Heretofore, fuel oil pressures on these installations were controlled by use of the conventional globe valve, but the short available control range immediately disqualified it for service use. The

* Naval Boiler and Turbine Laboratory, Navy Yard, Philadelphia, Pa.

problem confronting engineers was that of the production of a valve in which the pressure drop approximated a linear function of valve position over its entire range. In addition, it was considered desirable, from a safety standpoint, to incorporate a by-pass arrangement for prevention of accidental extinguishment of fires when approaching the closed position. For simplicity, an internal by-pass, directly actuated by the valve disc handle, was deemed preferable to one of an external design. A discussion of two valve designs, both fulfilling the above requirements, follows in subsequent paragraphs. Credit for a great deal of ingenuity and aid rendered to the various manufacturers during development work at the Naval Boiler and Turbine Laboratory may be given to Mr. J. Cacciola, Mechanical Engineer.

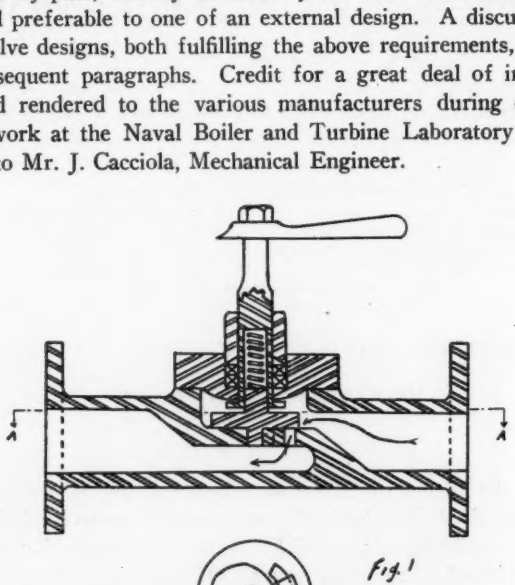


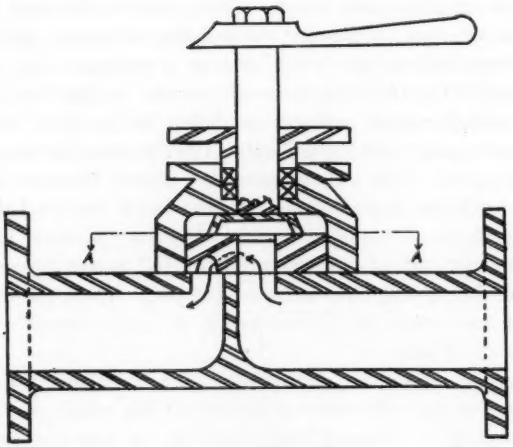
Fig. 1

Originally, several manufacturers submitted various forms of commercial "flow control" valves designed in general after the conventional ported sleeve valves. However, test work revealed flow characteristics falling short of those pursued. The first valve designed explicity for the above requirements is shown sketched in Figure 1. Oil entry is made on the topside of the disc, dis-

charging through an outlet port in the body of the valve. As shown, the free area of this port may be varied by circular movement of a logarithmic contoured disc, thereby governing flow characteristics. Thus, this arrangement may be likened to an iris diaphragm or adjustable orifice. Exit area, maintained in the wide open position by the disc, is designed to permit full power fuel oil requirement per boiler side at a pressure drop of approximately 10 p.s.i. The internal by-pass system was accomplished through use of one or more holes (in the disc) centering over the discharge port immediately after the disc has completely closed the port. The lap, between the closed position and the point at which the by-pass opens, amounts to 2 degrees-3 degrees. The quantity of oil supplied in this " by-pass " position is in the vicinity of one-half of that required for full power operation at a pressure drop through the valve of 225 p.s.i. Thus, the pressure at the burners would be approximately 75 p.s.i.—enough to prevent fires going out.

The second type valve, shown in Figure 2, utilized a logarithmic channeled disc; the channel starting at the center of the disc and decreasing in cross-sectional area in its sweep toward the periphery of the disc. Oil entry is made vertically into the center of the disc thence horizontally in the grove or channel and discharging through the outlet port in the body. Thus, flow characteristics are governed by the area of the channel adjacent to the outlet port. In addition, these characteristics are somewhat affected by the length of oil travel, i.e., the conduit length between the inlet and outlet ports offered by the channel. The by-pass arrangement is substantially the same as that of the preceding unit, i.e., use of a drilled hole centering over the discharge port immediately after disc closure.

Curves of typical flow characteristics applicable to both designs are shown in Figures 3 and 4. Data for these particular curves are representative for a unit having a capacity (wide open) of 10,000 pounds of fuel oil per hour at a pressure drop of 10 p.s.i. Figure 3 presents a set of curves showing pressure drop versus flow rate and clearly depicts the equality in flow distribution. Figure 4 is a plot of valve position versus pressure at the burners while utilizing full power sprayer plates (in this case, 10,000



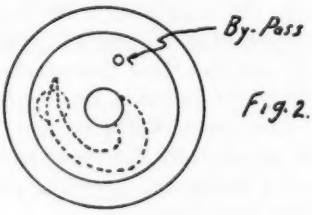


Fig. 2.

Section A-A

pounds per hour rate). The approach to straight line control, the answer to the subject problem, is very well illustrated in this curve. In this case, data were obtained by maintaining the inlet pressure constant at 300 p.s.i. and holding the discharge area at the size required to pass 10,000 pounds per hour, the hypothetical full power requirement. With the discharge area maintained constant, valve position was varied to obtain pressure drops ranging

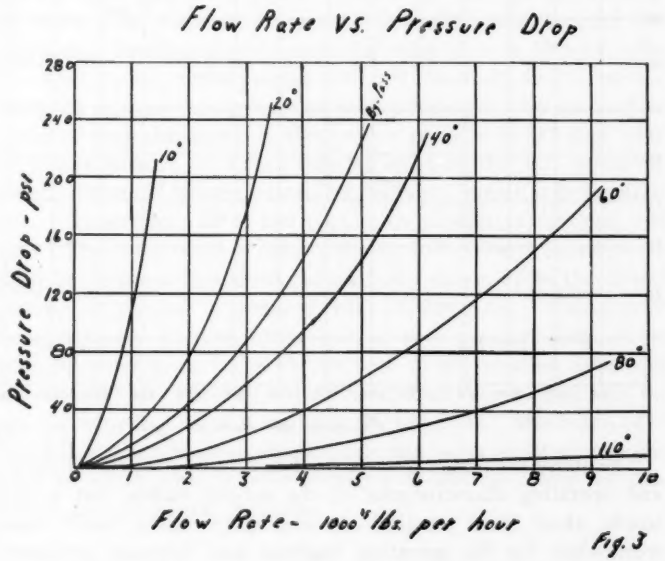


Fig. 3

from 25 to 250 p.s.i. Thus, these runs simulate the valve's intended use in controlling pressure in the fuel oil manifolds with a constant pump pressure. It is worthy to note the importance of selecting a valve commensurate with the actual fuel oil demands. Although one designed for a flow rate, say of 10,000 pounds per hour (wide open) could be used on a boiler requiring a maximum of only 5000 pounds per hour, the control sensitivity would be seriously reduced, particularly at the high firing rates. This is exemplified by the sharp upward trend of the dotted curve in Figure 4, the result of such an application.

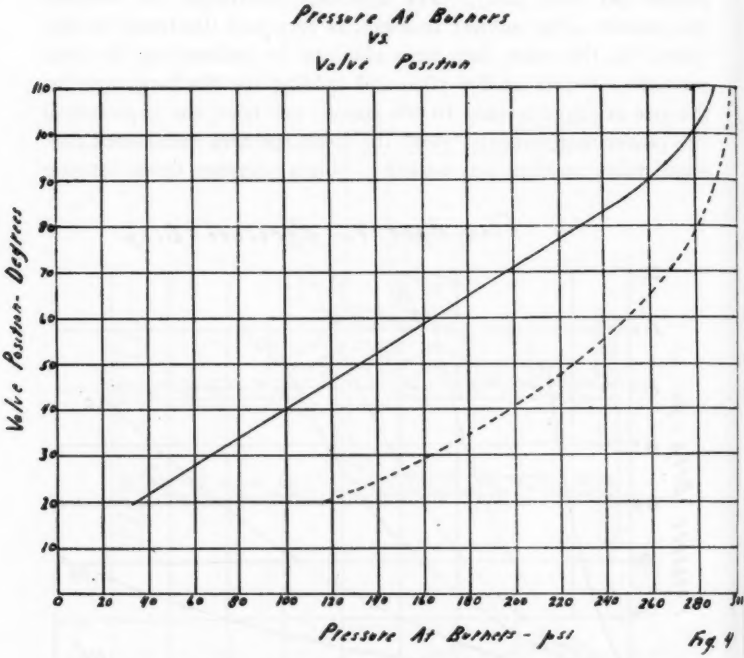


Fig. 4

The above discussion gives a brief insight of the general design and operating characteristics of the subject valves, but a few words about their practical use and specifications would seem worthwhile for the operating engineer and fireroom personnel. While setting and maintaining rates, the pressure gauge must be closely watched. Oil pressure gauges should be mounted to give the fireman a clear view during the throttling procedure. Although an indicating scale graduated in degrees is provided, the position shown is of no practical value and need not be noted. The fireman must never use this device as a quick closing valve under any circumstances. This is prohibited due to the critical closing range (2 degrees-3 degrees) between the closed and by-pass position. Any leakage which might develop will affect, in no way, operability and should cause no alarm. Emphasis is placed against use of wrenches or hammers for moving the hand lever—a practice inadvertently resorted to by the novice.

Materials of construction and detailed requirements pertinent to fuel oil control valves for Naval use are given in Bureau of Ships Ad Interim Specifications 45v30 (INT), January 2, 1942, highlights of which are presented here. The operating pressure for these units is stipulated at 350 p.s.i. Bodies, bonnets, and stems are to be fabricated from class b cast steel (49S2). Stems may also be made from class b forged steel (49S2), CRS class 10 (46S18), or cast CRS grade 7 (46S27). Bronze conforming to 46B8, CRS class 10, or cast CRS grade 7, may be used for the discs. Pressure drop through the valve is to be 10 p.s.i., plus 2, minus 1 p.s.i., when passing 150 SSU viscosity fuel oil at the designed capacity rating with an inlet pressure of 300 p.s.i. The pressure drop demanded in the by-pass position is 225 p.s.i. plus or minus 10 p.s.i. at a flow rate of one-half the full power or designed rate. Uniform control of discharge pressure is required over a range from 50 to 290 p.s.i. with an inlet pressure of 300 p.s.i. The valve position when utilizing full power sprayer plates shall be between 20 and 30 per cent of rotation from the closed position to produce a pressure drop of 250 p.s.i. With a port firing rate, the position corresponding to a pressure drop of 50 p.s.i. or more must be at 15 per cent of the rotation from the closed position. These flow features are, of course, premised on the use of a fuel oil at a viscosity of 150 SSU. Maximum permissible leakage between the disc and seat is set at 60 pounds per hour of water with an inlet pressure of 300 p.s.i. and the discharge at atmospheric pressure.

A REVIEW OF SPECTROGRAPHIC ANALYSIS OF SOME METALS AND ALLOYS.

By Dr. Jacob Sherman * and Mr. J. W. Jenkins †, Member.

Chapters I through VIII of this article were published in the May issue of the Journal. *Limitations of space made it impossible to publish the entire article at that time. The remainder, Chapters IX and X, appear below.*

A limited number of copies of the complete article are available in pamphlet form and may be purchased by application to the Society.

Chapter IX—*Methods* 404
Chapter X—*Plates* 465

CHAPTER IX.

METHODS.

The following methods, while of technical interest in themselves, are presented to illustrate the manner in which procedures were developed in the Industrial Test Laboratory. They were chosen to indicate the various techniques devised, using specimens in whatever form available, for the analysis of ferrous and non-

* Spectroscopist, Industrial Test Laboratory, U. S. Navy Yard, Philadelphia, Pa.
† Senior Materials Engineer, Bureau of Ships, Navy Department, Washington, D. C.

ferrous alloys, using arc and spark excitation, the Littrow and medium quartz spectrograph, the method of working curves and calibrated plates as well as the method of equal density line pairs and comparison with spectra of standards.

Methods 4 and 5, Analysis of "Zinc Spelter" and "Zinc Base Die Casting Alloy" illustrates the earliest types of procedures developed, i.e., arc excitation and comparison with standards. Methods 7 and 8, "Analysis of Pig Lead" and "Lead Battery Material" illustrate the increased accuracy of spark excitation and use of calibrated plates and working curves over direct comparison with spectra of standards. Methods 9, 10, 11, and 12, analysis of "Aluminum Alloys II (a)", "Aluminum Alloys II (b)" and Aluminum Alloys II (a), supplements "(a)" and "(b)" illustrate the increased accuracy of analytical results due to the use of standards approximating more closely the type of material being analyzed, as well as the way in which different methods of analysis may be combined for one sample to save time and still meet specification requirements.

Method 6, "Ingot Copper" illustrates the advantage of the method of equal density line pairs, (when possible), for the analysis of material under specification requirements. Methods 13, 14, and 15, "Steel IV(a)", "Steel IV(b)", and "Steel Solutions" illustrate the way in which availability of specimen (in regard to shape and size) controls the choice of analytical procedure.

It is regretted that methods using the recently installed light source, described and illustrated in other sections of the paper, are not ready for publication. It is expected to present a more critical, technical discussion of methods, particularly from the viewpoint of the effect of specimen availability on precision of results, at another time,

1. Calibration of a Photographic Plate.
2. Purification of Graphite Electrodes.
3. Aluminum Alloys I.
4. Zinc Spelter.
5. Zinc Base Die Casting alloy.
6. Ingot Copper.
7. Pig Lead.
8. Lead and Lead Battery Material.

9. Aluminum II (a).
10. Aluminum II (b).
11. Aluminum—supplement (a).
12. Aluminum—supplement (b).
13. Steel IV (a).
14. Steel IV (b).
15. Steel Solution.

1. THE CALIBRATION OF A PHOTOGRAPHIC PLATE.

Method I—Use of the Log Step Sector Disc.

Spectrograph:

(*a*) Bausch & Lomb Littrow.

Accessory:

(*a*) Bausch & Lomb Step Sector Disc with 8 steps of ratio 1.5 to 1.

Densitometer:

(*a*) Leeds & Northrup A. C. operated Speedomax Recording Microphotometer.

Electrodes:

(*a*) Massive Mild Steel Cones. (1).

Source:

(*a*) D. C. arc of 4 amperes.

Optics:

(*a*) Quartz. No condenser lens. Prism aperture at smallest stop.

Adjustment:

(*a*) Mount step sector disc 1/8 inch away from the slit of the spectrograph with the aperture on the step sector disc exactly centered over the spectrograph slit.

(*b*) Open the Hartmann diaphragm on spectrograph so that the slit is exposed to its entire length. Open the slit to its full width.

(*c*) Rotate the step sector disc so that the spectrograph slit is exposed to its entire length.

(*d*) Raise the back of the spectrograph. Open the slit shutter. With an arc of 4 amperes adjust the electrodes so that the image of

the arc is in the exact center of the prism both on horizontal and vertical planes. A white card held over the aperture stop, on the side toward the slit, will be found very convenient for this adjustment, particularly if the room is made semi-dark.

(*e*) Trim the arc so that the gap at the prism is close to 3/16 inch. Be sure there is no glow or incandescence at the electrodes. If there is, have the conical surfaces recleaned or resurfaced. The arc column as seen on the white card should be smooth, steady and burn with a bright blue flame, without any yellow streamers shooting away from the central column.

Slit:

(*a*) Full length. 35 microns wide.

Sector Speed:

(*a*) At least 2000 Rpm., but there must be absolutely no vibration.

Exposure:

(*a*) With the electrodes set at the proper adjustment, strike the arc by touching both electrodes near the vertices of the cones with a graphite electrode; with clean steel electrodes, properly centered, it will take only a few moments until the arc drifts to the exact cone vertices and burns quietly with only a slight rotary motion.

(*b*) Have the sector disc running smoothly before exposing the plate.

(*c*) Expose the plate long enough so that at least 6 steps (ratio 1.5 to 1) are readable on some single line at the desired wavelength. Approximate exposure time, for the conditions given in these directions for a spectrum analysis No. 1 plate, in positions 3, 5 and 7 are ½ minute, 1 minute and 2 minutes respectively. Multiply the time by 1.4 for a Process plate and by 0.8 for an Eastman 33 plate.

Development:

(*a*) Develop in strict accordance with the procedure used in the analysis of the materials under consideration.

Densitometry:

(*a*) Read at least 6 steps on some appropriate line at the wave length desired or chosen.

Construction of Curve:

(*a*) Use cross section paper ruled 20 × 20 to the inch.

(*b*) On the X axis (horizontal) mark off equal intervals (each one 17.6 units long) and numbered to correspond to the steps on the step sector disc. Step 1 should be the one of least aperture and step 8 the greatest aperture. Consequently, step 1, the lowest one on the photographed plate, will be the one of least density. The numbers should increase from left to right.

(*c*) On the Y axis (vertical) plot density. Each unit square on the chart paper should be .01 density units high.

(*d*) Mark the densities of the steps, as read, against the corresponding steps. The points as marked should fall on a smooth curve. Draw the curve. This curve is known as the Plate Calibration Curve, or H. & D. curve.

EXAMPLE (CURVE A).

Plate Emulsion—Spectrum Analysis No. 1

Wave Length Region—2900 A

1	*2*	*3*	*4*	*5*
Step	*X Axis Log Exposure*	*Y Axis Density*		*Log E for Line 2*
		Line (1)	*Line (2)*	
1	0	.100	.315	(.300)
2	.176	.205	.505	(.476)
3	.352	.365	.725	(.652)
4	.528	.568	.945	(.828)
5	.704	.790	1.165	(1.004)
6	.880	1.011	1.390	(1.180)
7	1.056	1.230	1.620	(1.356)
8	1.232	1.453		

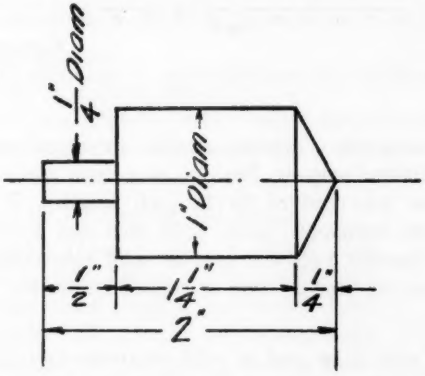
Column 1 Step Numbers
Column 2 Log E values of the steps for line 1
Column 3 Density values of line (1)
Column 4 Density values of line (2)
Column 5 Log E values for line (2)

(*a*) The curve may be drawn to a larger scale if so desired for purposes of greater accuracy.

(*b*) Line (1) is shown on the curve with the points indicated by (x).

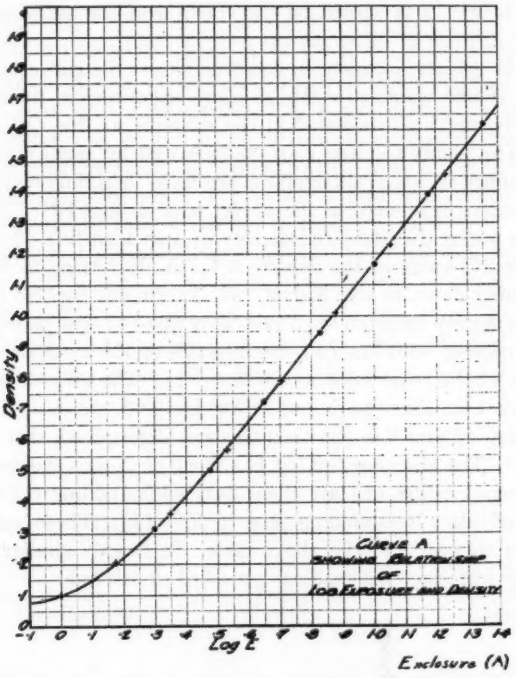
(*c*) If greater accuracy in construction of the curve is desired, that is, if one wants to establish more experimental points on it, a neighboring line, indicated in the example as line (2), may be read. The points for line (2) are indicated by small circles (o). The manner in which these points are fixed is as follows:

The curve is entered at the lowest step on line (2). That is, a circle is put at the measured density of step 1 on line (2). In the example this value of the density is 0.315. Referring to the curve and sliding down to the X-axis, one determines the log exposure for that density to be 0.300. Then, since line (2) was photographed simultaneously with line (1), the intervals on the log E or (x) axis for line (2) are the same as for line (1). The only difference is that step 1 on line (1) is put at log E=0.00, which is arbitrary, while step (1) on line (2) then becomes determined, that is fixed, at 0.300. The abscissae, or log E values, or X-axis values for the other steps on line (2) are then obtained by adding 0.300 to the values of the corresponding step in line (1). These values are given in column 5 of the above table. In exactly similar fashion one may introduce the readings on a 3rd or 4th line.



MASSIVE CONICAL ELECTRODE USED FOR PLATE CALIBRATION

FIGURE 1.



2. PREPARATION AND PURIFICATION OF GRAPHITE ELECTRODES.

Electrodes:

(*a*) Spectroscopic Carbons, similar to those made by the National Carbon Company, Inc.

(*b*) These are received in 12 inch lengths. Two different diameters are commonly used, 3/16 inch and 5/16 inch. The 3/16 inch diameter rods are used as solid electrodes. The 5/16 inch rods may be used as solid or cupped electrodes.

Preparation:

(*a*) The rods to be used as solid electrodes are cut into 2 inch lengths. The rods as received are nicked with a knife or hack saw blade and then broken by hand.

(*b*) The rods to be used as cupped electrodes are broken into 4 inch lengths. A hole 5/32 inch - 7/32 inch diameter and 3/16

inch - ¼ inch deep is drilled into both ends. A little cutter should be attached to the drill to flatten the end and round off the edges of the cut end. It is easier to drill both ends of a 4 inch rod than to drill one end of a 2 inch rod. Each 4 inch drilled piece is then nicked and broken in half.

Purification:

(*a*) *Acid Mixture:* 1 part HNO_3
3 parts HCl
12 parts H_2O

(*b*) The cut electrodes are immersed, say in a covered 2 liter beaker, in the acid mixture on a steam bath for 3 days. The acid is changed each day.

(*c*) The acid is then drained off, the electrodes rinsed with water and kept immersed in water in the beaker on the steam bath for 3 days. The water is changed each day. The last treatment should be with distilled water.

(*d*) The water is then drained off, the electrodes well washed with distilled water and dried in a porcelain dish on top of a hot plate.

(*e*) The finished electrodes should be kept in well covered bottles until ready for use.

3. SPECTROGRAPHIC METHOD OF ANALYSIS OF ALUMINUM ALLOYS I.

1. *Material and Method:*

(*a*) *Material:* Aluminum Alloys.

(*b*) *Method:* Rapid analysis for routine determination of conformity to specification. Visual comparison with spectra of standards; densitometric measurements.

2. *Elements to Be Determined and Range:*

Copper (Cu)	0.20% Max.
Manganese (Mn)	0.03%-1.4%
Magnesium (Mg)	0.03%-2.8%
Silicon (Si)	0.20%-5.0%
Tin (Sn)	.10% Max.
Zinc (Zn)	.30% Max.
Iron (Fe)	1.2% Max.
Chromium (Cr)	.03%-.35%
Titanium (Ti)	.20%

3. *Spectrograph:*

(*a*) *Type:* Bausch & Lomb large Littrow.

(*b*) *Spectral Range:* 2500 A to 3400 A. Position 5.

(*c*) *Slit Width:* 45 microns.

(*d*) *Slit Length:* 3 mm. Circular aperture on Hartmann diaphragm.

(*e*) *Aperture Stop:* Use smallest stop in front of the prism.

(*f*) *Internal Between Spectra:* 4 mm. apart in groups of 5. Between each group of 5 allow 5 mm.

(*g*) *Optics: Quartz.* Use condenser lens.

4. *Photographic Plate:*

(*a*) *Type:* Eastman Process.

(*b*) *Exposure Time:* 1 minute.

(*c*) *Development:* 4½ minutes in D19 at 68 degrees F. Fix in F5 for 10 minutes. Wash in running cold water for 15 minutes.

5. *Excitation or Source:*

(*a*) *Type:* A spark obtained from a Bausch & Lomb spark generator.

(*b*) *Adjustment:* Use inductance 60 (the greatest induction possible on the generator).

6. *Specimen and Standards:*

(*a*) *Preparation of Sample:* A flat surface, at least 1 inch × ½ inch and 3/32 inch thick is cleaned, using a belt grinder similar to the one used for rough grinding metallographic specimens. An aloxite belt, 80 grit, has been found very satisfactory for this purpose. If the specimen as received is not suitable (it may be a cylindrical piece such as the end of a tensile test specimen) then a flat surface can be machined using a lathe, shaper or milling machine. A shaper will be found to be the most useful machine for this purpose. The minimal size of the flat surface will depend in large measure upon the size of the holder used, as described below. In any case the smallest usable area is a circle about ½ inch diameter because the spark affected zone is a circle about ¼ inch in diameter.

(*b*) *Standards:* A series of standard aluminum specimens is necessary. These should contain the various alloying elements in

graded steps, says in steps of 0.20 per cent, throughout the entire range for which the analyses are made.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: The aluminum specimen under examination.

Lower: A pointed graphite rod (5/16 inch diameter). The graphite rod is sharpened to a point in a pencil sharpener. The pointed end is then inserted into the jig illustrated in Figure B and "B" in plate 1 and the extruding point is filed flush with the metal surface.

(*b*) The pointed graphite rod, prepared as described above is inserted into the fibre holder illustrated in Figure A and "A" in plate 1. The holder is then inserted over the gage block illustrated in Figure C and "C" in plate 1, so that the rim of the fibre rests on the larger cylinder while the tip of the electrode rests on the smaller one. The graphite electrode is then clamped on the fibre block with the thumb screw. The fibre block and graphite electrode are then held in the lower clamp of the spark stand on the spectrograph with the bottom of the fibre block resting on top of the clamp and the under opening turned toward the slit. The flat surface of the aluminum specimen prepared as described above, is then placed on top of the fibre block. Electrical contact with the aluminum is made by a graphite rod, held in the upper clamp of the spark stand, brought down so as to touch the aluminum piece on its upper surface. The electrode combination is then adjusted in a vertical plane so that the spark illuminates the exposed slit as symmetrically as possible.

After an exposure, the pressure of the upper graphite electrode against the aluminum specimen is relieved by moving the clamp holding the graphite rod. *Do not disturb the clamp holding the fibre block.* The aluminum specimen is removed and the fibre block taken out of the clamp with its contained graphite rod by springing the pairs of the clamp with a screw driver.

A new pointed graphite rod is then inserted into the fibre holder on the gage block and the electrode is ready for re-use. No further adjustment, in a vertical plane, of the clamp will be necessary.

It is advantageous to have at least two fibre blocks prepared, exactly the same size, particularly in length, so that one may be prepared while the other is in use.

8. *Reference Lines for Elements in Angstrom Units:*

Al	2660, 3050, 3057
Cu	3248, 3274
Mn	2889, 2933, 2939, 2949
Mg	2780, 2852, 2929, 2937
Si	2519, 2882
Sn	3175
Zn	3345
Fe	2598, 2599, 2739, 2749, 2756, 3020
Cr	2835, 2843, 2849
Ti	The group of lines just short of Cu 3248

9. *Densitometry:*

(*a*) *Type:* An indicating type densitometer similar to the Bausch & Lomb density comparator may be used. A recording densitometer, such as the Leeds & Northrup recording Micro-Photometer may also be used.

(*b*) The accuracy measurement should be sufficient to indicate a change in transparency ratio of .02.

10. *Analytical Procedure:*

(*a*) *Visual:* Suitable standard spectra are impressed on the plate. A visual comparison of the lines in the standard alloy and specimen being analyzed will usually determine its conformity or non-conformity. Best visual results are obtained when the aluminum line 3050, has a transparency of 0.35 and the ratio of transparency of

$$\frac{\text{Al } 3057}{\text{Al } 3050} \quad \text{is } 2.55.$$

(*b*) *Measurement:* When a closer estimate to the composition is desired, reference is made to a working curve prepared from the standards. Under the condition given below it is not necessary to calibrate the plate.

The following data is presented as typical:

Transparency of Al 3050=0.30

Ratio transparency

$$\frac{\text{Al } 3057}{\text{Al } 3050} = 2.55$$

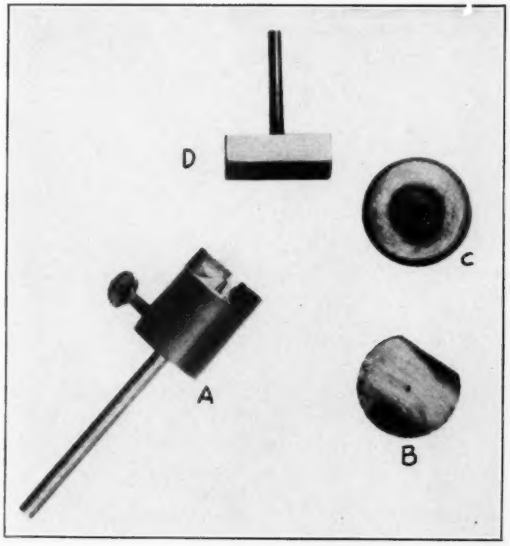


PLATE I.

Sp
belo

%
.10
.20
.40
.60
.80
1.00
1.20
1.40
1.60

Specimen working curve data for Mn, Mg, and Si are given below:

%	Ratio $\frac{\text{Si 2882}}{\text{Al 3050}}$	Ratio $\frac{\text{Mg 2780}}{\text{Al 3050}}$	Ratio $\frac{\text{Mn 2889}}{\text{Al 3050}}$	$\frac{\text{Mn 2933}}{\text{Al 3050}}$
.10		.22	.23	.22
.20	.37	.27	.27	.40
.40	.58	.43	.36	.80
.60	.78	.59	.46	1.20
.80	.98	.75	.55	1.60
1.00	1.18	.90	.65	2.00
1.20	1.38	1.07	74	2.40
1.40	1.60	1.23	.84	2.80
1.60	1.80	1.39		

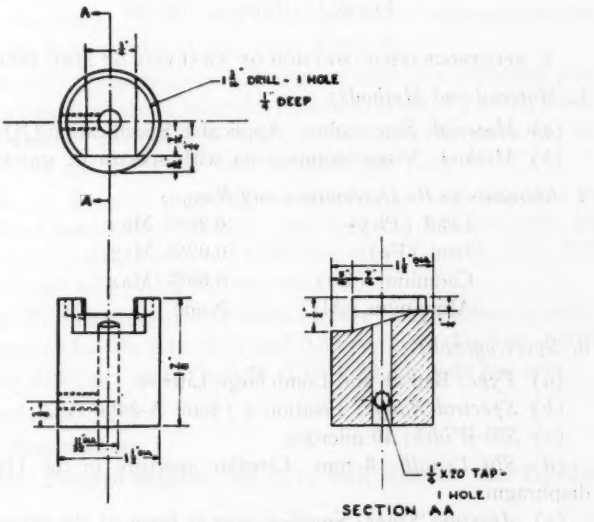


FIGURE A—MATERIAL—FIBER.

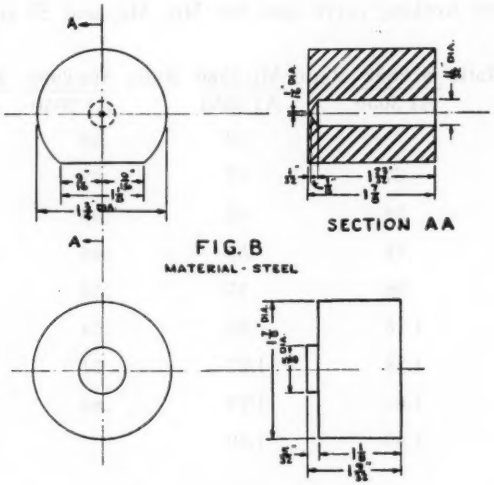


FIGURE C—MATERIAL—BRONZE.

4. SPECTROGRAPHIC METHOD OF ANALYSIS OF ZINC SPELTER.

1. *Material and Methods:*

(*a*) *Material:* Zinc spelter. Applicable Specification QQ-Z-351a.

(*b*) *Method:* Visual comparison with spectra of standards.

2. *Elements to Be Determined and Range:*

Lead (Pb)	0.20% Max.
Iron (Fe)	0.03% Max.
Cadmium (Cd)	0.50% Max.
Aluminum (Al)	None

3. *Spectrograph:*

(*a*) *Type:* Bausch and Lomb large Littrow.

(*b*) *Spectral Range:* Position 5 (2500 A-3400 A).

(*c*) *Slit Width:* 40 microns.

(*d*) *Slit Length:* 3 mm. Circular aperture in the Hartmann diaphragm.

(*e*) *Aperture Stops:* Smallest stop in front of the prism.

(*f*) *Interval Between Spectra:* 5 mm.

(*g*) *Optics: Quartz.* Use condenser lens.

4. *Photographic Plate:*

(*a*) *Type:* Eastman 33.

(*b*) *Exposure Time:* 2 minutes.

(*d*) *Development:* 4½ minutes in D19. Fix 15 minutes in F5. Wash 20 minutes.

5. *Excitation or Source:*

(*a*) *Type:* D. C. arc of 10 amperes.

6. *Specimen and Standards:*

(*a*) *Preparation of Sample:* 20 g. of zinc shavings are dissolved in 40 mls. concentrated HCl in a 200 cc. beaker (tall or electrolytic form). The acid is boiled vigorously and replenished as it is boiled off. After solution is complete the iron in the sample is oxidized with a few drops of nitric acid and the volume adjusted to 40 mls. using concentrated hydrochloric acid. *Do not use water.* 0.1 ml. of the solution is dropped into the cupped electrode and dried for 2 hours in an oven at 110 degrees C. *Do not expose the electrode to the air before using. If necessary, store in a desiccator.*

(*b*) *Standards:* Three series of standards are necessary to take care of the three grades of zinc, A-1, A and B.

Grade A-1: Prepare a graded series of pure zinc solutions, prepared as described above, to which have been added Pb 0.002, 0.004, 0.006 and 0.008 per cent; Fe 0.002, 0.004 and 0.006 per cent; Cd 0.002, 0.004 and 0.006 per cent; Al 0.002 per cent.

Grade A: Prepare a graded series of pure zinc solutions to which have been added Pb 0.02, 0.04, 0.06 and 0.08 per cent; Fe 0.005, 0.010, 0.015, 0.020 and 0.025 per cent; Cd 0.02, 0.04, 0.06 and 0.08 per cent; Al 0.02 per cent.

Grade B: Prepare a graded series of pure zinc solutions to which have been added Pb 0.10, 0.15 and 0.20 per cent; Fe 0.01, 0.015, 0.02 and 0.025 per cent; Cd 0.20, 0.40, 0.50 and 0.60 per cent.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: Purified graphite rod 5/16 inch diameter and 2 inches long.

Lower: Purified cupped graphite electrode, 5/16 inch in diameter.

(*b*) *Adjustment:*

Trim the electrodes so that they are sharply imaged just above and below the exposed slit. Start the arc by touching the electrodes with a graphite rod.

(*c*) *Gap:* 5/32 inch.

It is necessary to trim the electrodes during the exposure to compensate for the graphite consumed.

8. *Reference Lines for the Elements in A:*

Pb	2873, 2833, 2663
Fe	3020
Cd	3261, 2980
Al	3093, 3082

9. *Densitometry:*

(*a*) No densitometer is used.

10. *Analytical Procedure:*

(*a*) The lines of the impurity elements in the specimen are compared with the corresponding lines in the spectra of the standards impressed on the same plate.

(*b*) If so desired, a preliminary spectrum of the specimen may be made and the impurity lines compared with the impurity lines in the spectra of the standards on another plate. The spectrum of the specimen is then retaken with the appropriate standards on the same plate.

5. SPECTROGRAPHIC METHOD OF ANALYSIS OF ZINC BASE DIE CASTING ALLOY.

1. *Material and Methods:*

(*a*) *Material:* Zinc Base Die Casting Alloy. Applicable Specification 46-Z-2.

(*b*) *Method:* Visual comparison with spectra of standards.

2. *Elements to Be Determined and Range:*

Copper (Cu)	.03% Max.
Magnesium (Mg)	.03-.08%
Iron (Fe)	.10% Max.
Lead (Pb)	.007% Max.
Cadmium (Cd)	.005% Max.
Tin (Sn)	.005% Max.

3. *Spectrograph:*

(*a*) *Type:* Bausch & Lomb large Littrow.

(*b*) *Spectral Range:* Position 5 (2500 A-3400 A).

(*c*) *Slit Width:* 40 microns.

(*d*) *Slit Length:* 3 mm. Circular aperture in the Hartmann diaphragm.

(*e*) *Aperture Stops:* Smallest stop in front of the prism.

(*f*) *Interval Between Spectro:* 4 mm.

(*g*) *Optics:* Quartz. Use condenser lens.

4. *Photographic Plate:*

(*a*) *Type:* Eastman 33.

(*b*) *Exposure Time:* 2 minutes.

(*d*) *Development:* 4½ minutes in D19. Fix for 15 minutes in F5. Wash 20 minutes.

5. *Excitation or Source:*

(*a*) *Type:* D. C. arc of 10 amperes.

6. *Specimen and Standards:*

(*a*) *Preparation of Sample:* 20 g. of sample turnings are dissolved in an equal volume mixture of concentrated hydrochloric and nitric acids. After the solution is completed, the volume is adjusted to 60 mls. with nitric acid. 0.1 ml. of the solution is dropped into the cup of the graphite electrode and dried in an oven at 110 degrees C. for 2 hours.

(*b*) *Standards:* Prepare 2 solutions of pure zinc as above, and add 4 per cent Aluminum. Adjust one solution (called the low standard) to contain 0.03 per cent Mg and the maximum amount of the other impurities allowed. Adjust the other solution (called the high standard) to contain 0.08 per cent Mg and the maximum amount of the other impurities.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: Purified graphite rod 5/16 inch diameter and 2 inches long.

Lower: Purified cupped graphite electrode 5/16 inch in diameter.

(*b*) *Adjustment:* Trim the electrodes so that they are sharply imaged just above and below the exposed slit. Start the arc by touching the electrodes with a graphite rod.

(*c*) *Gap:* 5/32 inch. It is necessary to trim the electrodes during the exposure to compensate for the graphite consumed.

8. *Reference Lines for the Elements, in Angstrom Units:*

Mg	The five lines centering about 2780, i.e. 2782.99, 2781.43, 2779.85, 2778.29, 2776.71.
Cu	3274, 3248.
Fe	3020.
Pb	2833, 2614.
Cd	3261.
Sn	3175, 2840.

9. *Densitometry:*

(*a*) No densitometer is used.

10. *Analytical Procedure:*

(*a*) The lines of the impurity elements in the specimen are compared with the corresponding lines in the spectra of the two standards taken on the same plate. A hand magnifier or projector may be used.

6. SPECTROGRAPHIC METHOD OF ANALYSIS OF INGOT COPPER.

1. *Material and Method:*

(*a*) *Material:* Ingot Copper. Applicable Specification 46-C-5c.

(*b*) *Method:* Visual inspection of equal density line pairs.

2. *Elements to Be Determined and Range:*

Bismuth (Bi)	0.001% Max.
Antimony (Sb)	0.0025% Max.
Arsenic (As)	0.0025% Max.
Iron (Fe)	0.004% Max.
Lead (Pb)	0.005% Max.

3. *Spectrograph:*

(*a*) *Type:* Bausch & Lomb large Littrow.

(*b*) *Spectral Range:* Position 5 (2500 A to 3400 A). Position

7 (2300 A to 2900A).

(*c*) *Slit Width:* 45 microns.

(*d*) *Slit Length:* 3 mm. Circular aperture on Hartmann diaphragm.

(*e*) *Aperture Stops:* Smallest stop before prism.

(*f*) *Interval Between Spectra:* 4 mm.

(*g*) *Optics: Quartz.* Use condenser lens.

4. *Photographic Plate:*

(*a*) *Type:* Eastman 33.

(*b*) *Exposure Time:* 2 minutes in position 7 and 1 minute in position 5. There should be a distinct background in both positions, particularly at 2300 A.

(*c*) *Calibration:* No calibration is used. However, the spectrum in position 5 should show Cu 2844.2 A=2845.0 A.

(*d*) *Development:* 4½ minutes in D19. Fix 15 minutes in F5. Wash 20 minutes in cool running water.

5. *Excitation or Source:*

(*a*) *Type:* D. C. arc of 5 amperes.

6. *Specimen and Standards:*

(*a*) *Preparation of Sample:* A chip of the sample (0.2-0.5 gram) should be cleaned in dilute hydrochloric acid (1:3), washed with distilled water and dried on filter paper before use. *Do not handle the wet chip with metal tweezers or tongs.*

(*b*) *Standards:* Normal standards may be made from copper ingot previously analyzed by wet chemical methods. A range of impurities may be made from pure cuprous oxide as a base to which appropriate amounts of oxides of Bi, Sb, As, Fe and Pb have been added.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: Positive electrode. Pure copper rod 4 mm. in diameter. Should be cleaned in dilute (1:4) nitric acid before use.

Lower: Negative electrode. A chip (0.2-0.5 gram) of the sample supported in a shallow depression (1/16 inch deep and ¼ inch diameter) in the end of a graphite electrode 5/16 inch diameter and 2 inches long.

(*b*) *Adjustment:* Trim the electrode so that the gap is about 3 mm. Start the arc by touching the copper rod and chip with a 3/16 inch diameter pure graphite rod. It is best to begin the arc with a momentary current of 7 amperes. Let the copper chip fuse to a globule and then carefully adjust the current exactly to 5 amperes. The spectrum is ready to be taken after the specimen has fused to a globule and the arc strikes directly upon it with only a slight rotary motion. If the arc strikes the graphite rod or the sample adheres to the copper rod the electrode should be manipulated, that is, the gap should be carefully opened and closed, until a quiet, steady fusion is obtained. The copper specimen should appear as a light green incandescent bead. This should be achieved in not more than 30 seconds. If the desired result is not obtained in that time a new chip should be used. A little practice will soon enable the operator to produce this "globular arc" in 20 seconds or less. Take the spectra first in position 7 and then in position 5. Total elapsed time of burning on one chip should not be more than 5 minutes. Both spectra may be taken from the same bead. If the indicated time is exceeded take each spectrum from a different chip.

(*c*) *Gap:* 4 mm. centered over the slit. The images of the electrodes should be sharply defined above and below the exposed slit.

8. *Reference Lines in Angstrom Units:*

Cu:	3068.906	*2845.0	*2844.2	2630.004
	*2627.1	*2570.7	*2479.8	2363.21

* Not given in Harrison's "Wave Length Tables."

Bi	3067.7
Sb	2598.
As	2349.8
Fe	2483.3
Pb	2614.2

9. *Densitometry:*

(*a*) No densitometer is used.

10. *Analytical Procedure:*

(*a*) The line pairs given below are examined visually for relative density or blackness either through a hand lens or by projection on a screen.

BI

% Bi	*Bi Line*	*Cu Line*
0.0002	3067.7	=3068.9
.0005		more than 3068.9

SB

% Sb	*Sb Line*	*Cu Line*
0.015	2598.	less than 2630.0
		more than 2627.5
.002	2598.	less than 2577.1

AS

% As	*As Line*	*Cu Line*
0.001	2349.8	(barely visible)
.003	2349.8	less than 2363.3
.01	2349.8	more than 2363.3

FE

% Fe	*Fe Line*	*Cu Line*
0.002	2483.3	less than 2479.8
.005	2483.3	=2479.8

PB

% Pb	*Pb Line*	*Cu Line*
0.001	2614.2	less than 2627.5
.005	2614.2	more than 2627.5
		less than 2630.004

7. SPECTROGRAPHIC METHOD OF ANALYSIS OF LEAD PIG.

1. *Material and Methods:*

(*a*) *Material:* Lead, pig. Grade A. Applicable Specification QQ-L-171.

(*b*) *Method:* Visual comparison with spectra of standards.

2. *Elements to Be Determined and Range:*

Copper (Cu)	.10% Max.
Bismuth (Bi)	.10% Max.
Silver (Ag)	.10% Max.
Nickel (Ni)	.10% Max.
Cobalt (Co)	.10% Max.
Antimony (Sb)	.10% Max.
Arsenic (As)	.10% Max.
Tin (Sn)	.10% Max.
Iron (Fe)	.10% Max.

3. *Spectrograph:*

(*a*) *Type:* Bausch & Lomb large Littrow.

(*b*) *Spectral Range:* Position 5 (2500 A-3400 A).

(*c*) *Slit Width:* 45 microns.

(*d*) *Slit Length:* 3 mm. Circular aperture in the Hartmann diaphragm.

(*e*) *Aperture Stops:* Smallest stop in front of prism.

(*f*) *Interval Between Spectra:* 5 mm.

(*g*) *Optics:* Quartz. Use condenser lens.

4. *Photographic Plate:*

(*a*) *Type:* Eastman Process.

(*b*) *Exposure Time:* 2 minutes.

(*d*) *Development:* 4½ minutes in D19. Fix 10 minutes in F5. Wash 15 minutes.

5. *Excitation or Source:*

(*a*) *Type:* D. C. arc of 15 amperes.

6. *Specimen and Standards:*

(*a*) *Preparation of Specimen:* 20 g. of turnings are dissolved in a solution of 20 mls. nitric acid and 80 ml. of distilled water in a 200 ml. Erlenmeyer flask, covered with a cover glass. The solution is gently warmed until a perfectly clear solution results. After the sample has gone completely into solution, sufficient distilled water shall be added to bring the volume up to 100 ml. (With proper care and using only gentle heat, no addition of water will be necessary). 0.1 ml. of the solution is dropped into the electrode

cup and the electrode dried in an oven at 110 degrees C. for 1 hour, until the liquid has evaporated and a crust of salts is in the electrode cup. If there is a cloudiness in the solution due to excessive Sb or Sn the sample is dissolved as described under "Lead Storage Battery Alloy".

(*b*) *Standards:* Prepare solutions of pure Pb to which the desired elements have been added in steps of .002 per cent.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: A purified graphite rod 5/16 inch in diameter and 2 inches long.

Lower: A purified cupped graphite electrode.

(b) *Adjustment:* The electrodes are centered so that the images of them are sharply defined just above and below the exposed slit. The arc is started by touching the electrodes with a piece (12 inches) of 5/16 inch graphite rod.

(*c*) *Gap:* 5/32 inch. The gap should be trimmed during the exposure to compensate for the graphite consumed during the exposure.

8. *Reference Lines for the Elements in Angstroms:*

Cu	3248, 3274	Co	3405
Bi	2989, 3067	Sb	2598
Ag	3280, 3382	Sn	2840, 3175
Ni	3002, 3414	Fe	3020

9. *Densitometry:*

(*a*) No densitometer is used.

10. *Analytical Procedure:*

(a) Have a plate with the spectra of the standards ready for reference.

(b) Take a preliminary plate of the specimens.

(*c*) Compare the impurity lines in the spectra of the specimens with those on the standard plate for a first approximation.

(*d*) Take the spectra of the specimens and of sufficient standards on the same plate and by visual comparison of impurity lines, either with a hand lens or by projection, estimate the concentrations of the impurities.

(*e*) If the presence of As is suspected, analyze as described under "Lead Storage Battery Alloys".

8. SPECTROGRAPHIC METHOD OF ANALYSIS OF LEAD AND BATTERY ALLOYS.

1. *Material and Method:*

(*a*) *Material:* Lead and Lead Battery Alloys.

(*b*) *Method:* Rapid analysis for routine determination of conformity to specification. Visual comparison with spectra of standards; comparison of equal density line-pairs; densitometric measurements.

2. *Elements to Be Determined and Range:*

Silver (Ag)	0.002 — 0.015%
Bismuth (Bi)	0.02 — 0.15%
Copper (Cu)	0.002 — 0.15%
Arsenic (As)	0.015 — 0.17%

3. *Spectrograph:*

(*a*) *Type:* Bausch & Lomb Medium Quartz.

(*b*) *Slit Width:* 0.025 mm.

(*c*) *Slit Length:* 2.5 mm. Circular aperture on Hartmann diaphragm.

(*d*) *Aperture Stop:* Elliptical stop all the way down.

(*e*) *Interval Between Spectra:* 3 mm.

(*f*) *Optics:* No condenser lens.

(*g*) *Distance of Spark to Slit:* 18 inches.

4. *Photographic Plate:*

(*a*) *Type:* Eastman Spectrum Analysis No. 1.

(*b*) *Exposure Time:* Dark spectra.—30 seconds, no presparking Light spectra.—5 seconds immediately after exposure for dark spectrum.

(*c*) *Calibration:* The plate is calibrated at 2400A and at 3200A using a direct current arc of 5 amperes between massive copper electrodes and a rotating logarithmic step sector.

(*d*) *Development:*

Develop: 4 minutes in Eastman Formula D19 at 68 degrees F.
Fix: 3 minutes in Eastman Formula F5.
Wash: 15 minutes in running cold tap water.

5. *Excitation or Source:*

(*a*) *Type:* Bausch and Lomb spark generator.
(*b*) *Adjustment:* Inductance at 100 (20 microhenrys).

6. *Specimens and Standards:*

(*a*) *Preparation of Sample:* A steel mold is used to compress the sample into a short rod ¼ inch in diameter and approximately ¼ inch in length. The mold is used in conjunction with a hand press such as an ordinary pill press. A sufficient number of small pieces of the sample is placed into the mold and the sample is compressed into a rod by applying pressure to the plunger of the mold by means of the handpress. One surface of the rod so obtained is then filed to a flat surface using a coarse file.

(*b*) *Standards:* A series of standard samples was prepared by melting together in vacuum weighed quantities of high purity lead and the requisite quantities of carefully analyzed lead-silver, lead-bismuth, lead-copper and lead-arsenic hardeners. The standard samples thus prepared were of such composition that the bismuth, copper and arsenic contents increased in steps of 0.025 per cent and the silver content increased in steps of 0.0025 per cent over the entire range of each element to be determined.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: A 5/16-inch graphite rod about 2 inches long is sharpened to a point in a pencil sharpener. The point is then filed to a flat surface about 2 mm. in diameter and is made ready for use by sparking to a flat piece of graphite until the point has been worn down to a spherical top about 3 mm. in diameter. The diameter of the top is conveniently measured by means of a hand measuring lens. The electrode is changed for every sample.

Lower: A graphite rod 5/16 inch in diameter and approximately 2 inches long recessed at one end is used as a support for the prepared sample.

(*b*) *Adjustment:* The Bausch and Lomb arc and spark stand is used, the electrode holders being so adjusted that the center of the spark gap is on the optic axis of the spectrograph. After adjustment of the positions of the electrodes, the electrode position indicator and spacer is fixed and is used to make future adjustments of the electrode positions to give a spark gap of ⅛ inch. With the shutter of the spectrograph open the sample is sparked for 30 seconds, the shutter is then closed while the plate holder is moved 3 mm. and the shutter is opened. The plate is exposed for 5 seconds and then the spark is stopped.

8. *Reference Lines for Elements in Angstrom Units:*

Pb: 3221, 2628, 2332	As: 2350
Cu: 3274	Ag: 3383
Bi: 3068	

9. *Densitometry:*

(*a*) *Type:* Leeds and Northrup a-c operated recording microphotometer.

(*b*) Visual examinations are made using a hand lens or by projection.

10. *Analytical Procedure:*

(*a*) *Visual:* Suitable standards are impressed on the plate. A visual comparison of the lines in the spectra of the standard samples being analyzed is then made.

(*b*) *Equal Density Line Pairs:* The following equal density line-pairs are suggested as an aid to rapid visual examination.

COPPER

Spectrum	*% Cu*	*Cu*	*Pb*
Dark	0.003	3274	3221
Light	0.025	3274	2628

SILVER

Spectrum	*% Ag*	*Ag*	*Pb*
Dark	0.0065	3383	3221

BISMUTH

Spectrum	*% Bi*	*Bi*	*Pb*
Dark	0.04	3068	3221

ARSENIC

Spectrum	*% As*	*As*	*Pb*
Dark	0.07	2350	2332

(*c*) *Densitometric Readings and Working Curves:* Working curves are obtained by plotting the difference in the logarithm of intensities against per cent element to be determined using the following lines:

COPPER

Cu 3274 — Pb 3221 range: 0.002 — 0.15%

SILVER

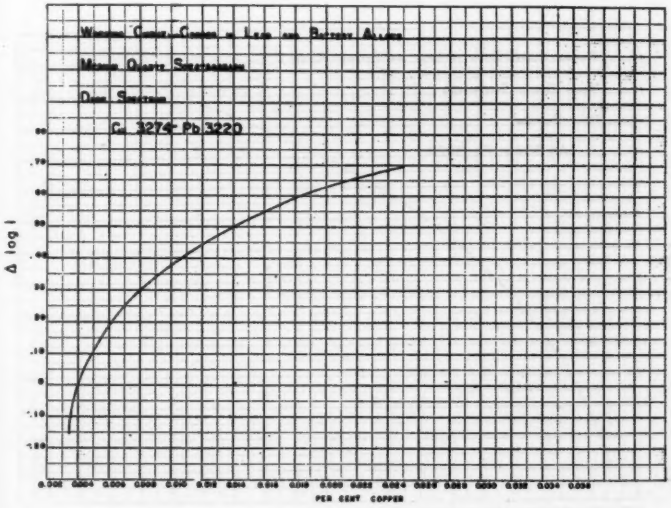
Ag 3383 — Pb 3221 range: 0.002 — 0.015%

BISMUTH

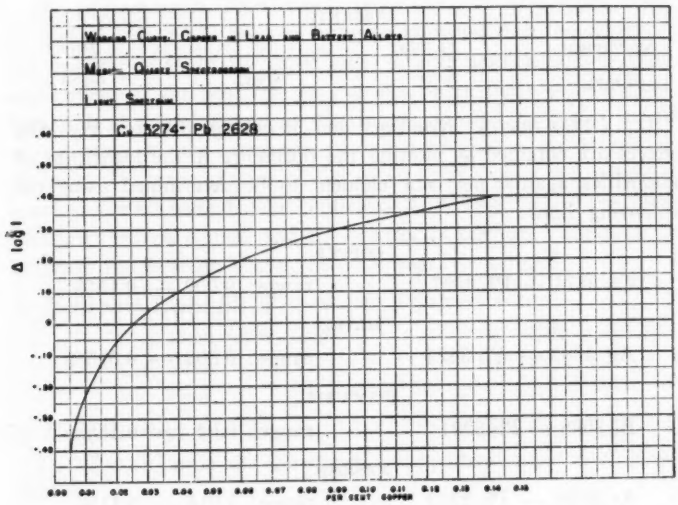
Bi 3068 — Pb 3221 range: 0.02 — 0.15%

ARSENIC

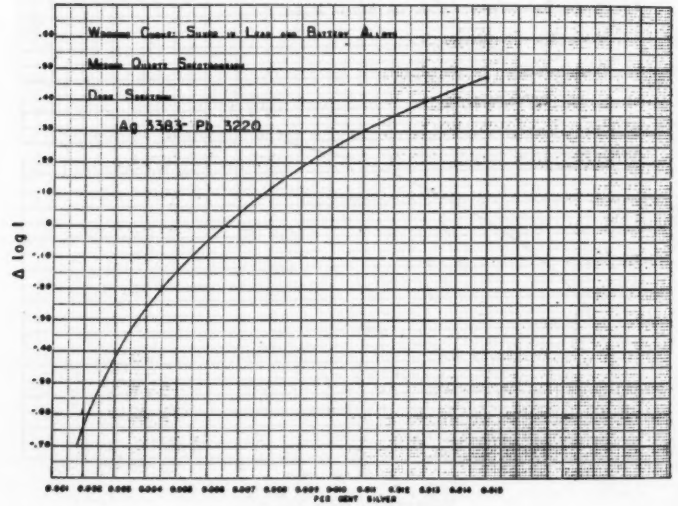
As 2350 — Pb 2332 range: 0.015 — 0.17%



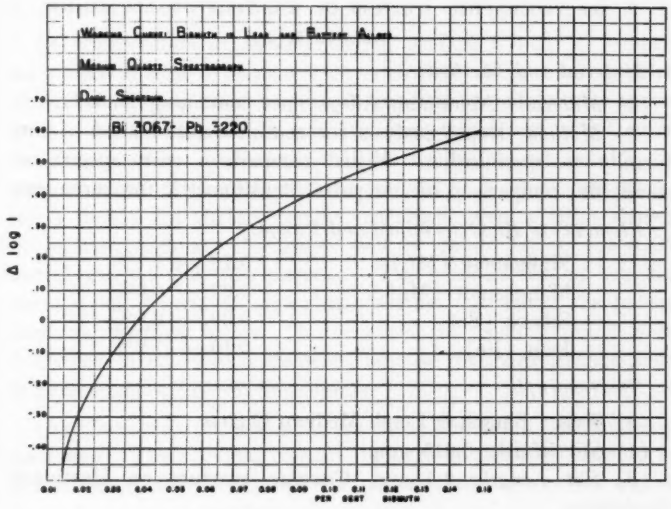
WORKING CURVE NO. 1.


Working Curve: Copper in Lead and Battery Alloys
Method: Quartz Spectrograph
Light: Spectrum
Cu 3274 - Pb 2628
Δ log I
PER CENT COPPER

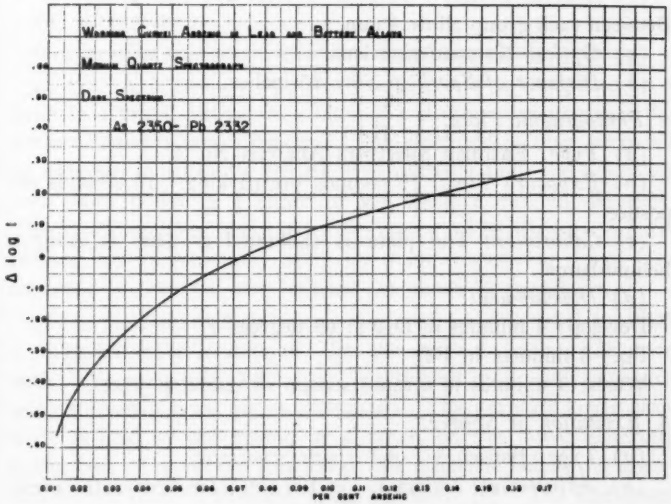
Working Curve No. 2.


Working Curve: Silver in Lead and Battery Alloys
Method: Quartz Spectrograph
Light: Spectrum
Ag 3383 - Pb 3220
Δ log I
PER CENT SILVER

Working Curve No. 3.



WORKING CURVE No. 4.



WORKING CURVE No. 5.

9. SPECTROGRAPHIC METHOD OF ANALYSIS OF ALUMINUM ALLOYS II(A).

1. *Material and Method:*

(*a*) *Material:* Aluminum Alloys (not containing Nickel).

(*b*) *Method:* Rapid analysis for routine determination of conformity to specification. Visual comparison with spectra of standards; comparison of line-pairs; densitometric measurements.

2. *Elements to Be Determined and Range:*

Manganese (Mn)	0.10 — 1.7%
Magnesium (Mg)	0.20 — 4.0%
Silicon (Si)	0.20 — 6.5%
Iron (Fe)	0.10 — 1.2%

3. *Spectrograph:*

(*a*) *Type:* Bausch & Lomb Medium Quartz.

(*c*) *Slit Width:* 0.015 mm.

(*d*) *Slit Length:* 2.5 mm. Circular aperture on Hartmann diaphragm.

(*e*) *Aperture Stop:* Elliptical stop all the way down.

(*f*) *Interval Between Spectra:* 3 mm. apart in groups of 5. Between each group allow 4 mm.

(*g*) *Optics:* No condenser lens.

(*h*) *Distance of Spark to Slit:* 25 inches.

4. *Photographic Plate:*

(*a*) *Type:* Eastman Spectrum Analysis No. 1.

(*b*) *Exposure Time:* 10 seconds presparking. 10 seconds exposure.

(*c*) *Calibration:* The plate is calibrated at 2900 A using a helium lamp.

(*d*) *Development:*

Develop: 4 minutes in D19 at 68 degrees F.

Fix: 3 minutes in F5.

Wash: 3 minutes in a rapid stream of cold tap water.

5. *Excitation or Source:*

(*a*) *Type:* Bausch & Lomb spark generator.

(*b*) *Adjustment:* Inductance at 100 (20 microhenrys, the greatest induction possible on the generator).

6. *Specimen and Standards:*

(*a*) *Preparation of Sample:* A flat surface 1 inch × ½ inch on a piece at least 3/32 inch thick is cleaned, using a belt grinder similar to the one used for rough grinding metallographic specimens. An aloxite belt, 80 grit, has been found very satisfactory for this purpose. If the specimen as received is not suitable (it may be a cylindrical piece such as the end of a tensile test specimen) then a flat surface can be machined using a lathe, shaper or milling machine. A shaper will be found to be the most useful machine for this purpose. The minimal size of the flat surface will depend in large measure upon the size of the holder used, as described below. In any event the smallest usable area is a circle about ½ inch diameter, because the spark affected zone is a circle about ¼ inch in diameter.

(*b*) *Standards:* A series of standard aluminum specimens is necessary. These should contain the various alloying elements in graded steps, say in steps of 0.2 per cent throughout the entire range for which the analyses are made.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: The aluminum specimen under examination.

Lower: A 5/16-inch diameter graphite rod is sharpened to a point in a pencil sharpener. The point is then filed to give a flat surface about 1 mm. diameter. The electrode is then prepared by sparking it against a flat piece of graphite until the point has been worn down to a spherical top about 2 mm. in diameter. This sparking takes about 1 to 2 minutes. The diameter of the pointed top is measured using the hand measuring lens. An electrode so prepared may be used for about 50 specimens.

(*b*) *Adjustment:* A fixture is prepared, as illustrated in Plate 1. The fixture is so designed that the spark is just on the optic axis. The spark gap, 5/32 inch, is adjusted after each exposure using the small brass jig as illustrated. The graphite lower electrode is held by the spring in a notch on the lower electrode holder bar. The proper location of the electrode below the specimen holder plate is adjusted using the brass jig. The aluminum

specimen is then placed over the V-notch of the specimen holder plate and the electrodes are ready for excitation. The specimen is sparked for 10 seconds with the slit shutter closed; the shutter is opened at 10 seconds and the plate is exposed for 10 seconds. The shutter is then closed and the spark shut off.

8. *Reference Lines for Elements in Angstrom Units:*

Al: 3996, 3060, 3057, 3050, 2660, 2652, 2322.
Mn: 4031, 2949, 2939, 2933, 2890, 2801, 2606.
Mg: 3097, 2937, 2929, 2791, 2783, 2780.
Si: 2882, 2516, 2507.
Fe: 2740, 2599.

9. *Densitometry:*

(*a*) *Type:* Leeds & Northrup a-c operated recording microphotometer.

(*b*) Visual examinations are made using a hand lens or by projection.

10. *Analytical Procedure:*

(*a*) *Visual Comparison with Standards.*

Suitable standard spectra are impressed on the plate. A visual comparison of the lines in the standard alloy and the specimen being analyzed is then made.

(*b*) *Line Pairs:* The following line pairs are suggested as an aid to rapid visual examination. When the indicated lines appear equally dense the concentration of the alloying element is as given in column 1.

TABLE I.

MANGANESE

% Mn	*Mn*	*Al*
0.2	2949	3050
.25	2606	2652
.4	2890	3060
.5	2801	3050
.8	4031	3996
Above 1.0	2949	3057

TABLE II.

MAGNESIUM

% Mg	*Mg*	*Al*
Below 0.05	2852	3050
.25	2791	2652
.4	2937	3050
.6	2780	2322
.8	2929	3050
.8	2780	3050
1.2	3097	3060
1.4	2780	2652
1.5	2929	3057
2.5	2783	3050
Above 3.0	3097	3050

TABLE III.

SILICON

% Si	*Si*	*Al*
0.3	2516	2322
.8	2882	3050
.9	2507	2322
1.0	2516	2652
2.0	2882	2652

TABLE IV.

IRON

% Fe	*Fe*	*Al*
0.1	2599	2322
.4	2599	2652
1.0	2740	2652

(*c*) *Densitometric Reading and Working Curve:* Working curves are prepared by plotting the difference of log intensity against the per cent of the element sought using the following lines:

MANGANESE

Mn 2939 — Al 3050	range: 0.1 — 1.7%
Mn 2933 — Al 3050	range: 0.3 — 1.7%

MAGNESIUM

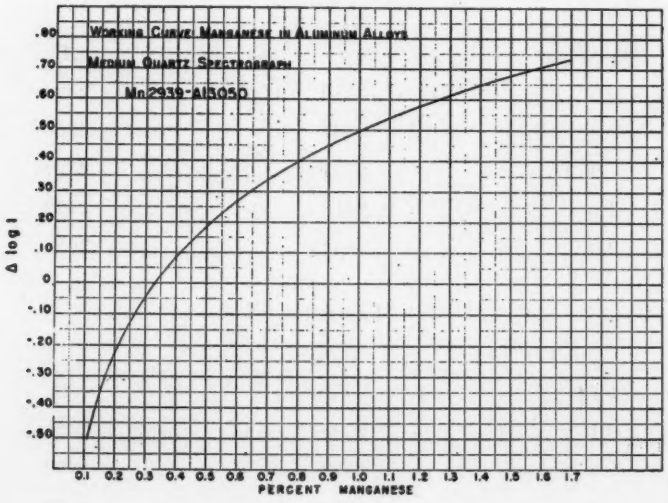
Mg 2929 — Al 3050	range: 0.4 — 4.0%

SILICON

Si 2507 — Al 3050	range: 1.0 — 6.0%
Si 2516 — Al 3057	range: .3 — 6.0%

IRON

Fe 2599 — Al 3050	range: 0.1 — 1.3



WORKING CURVE NO. 1.

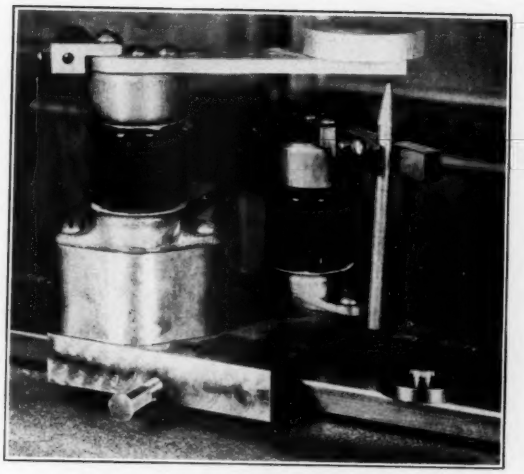


PLATE 1 (a).

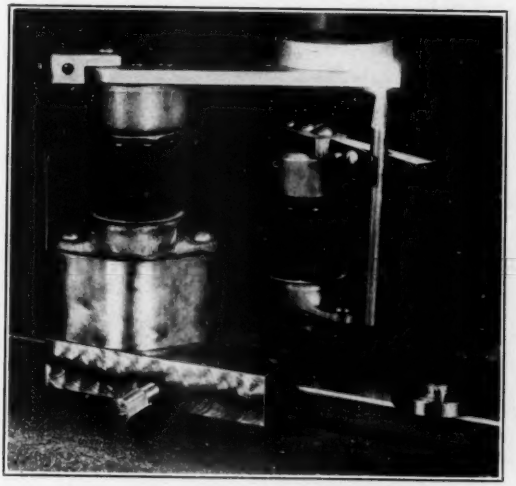
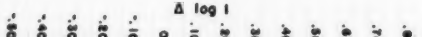
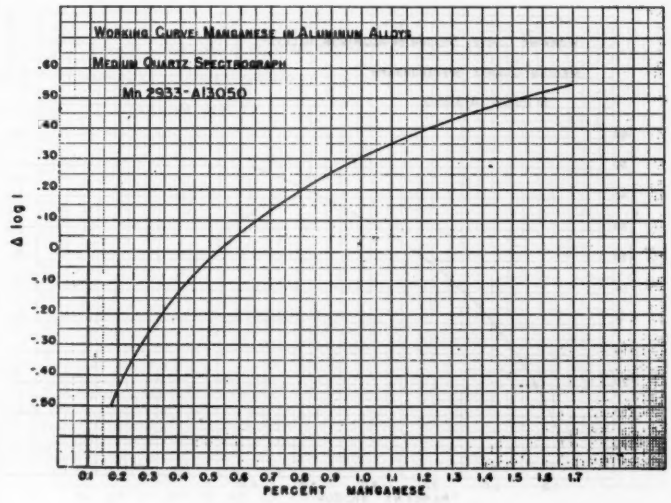


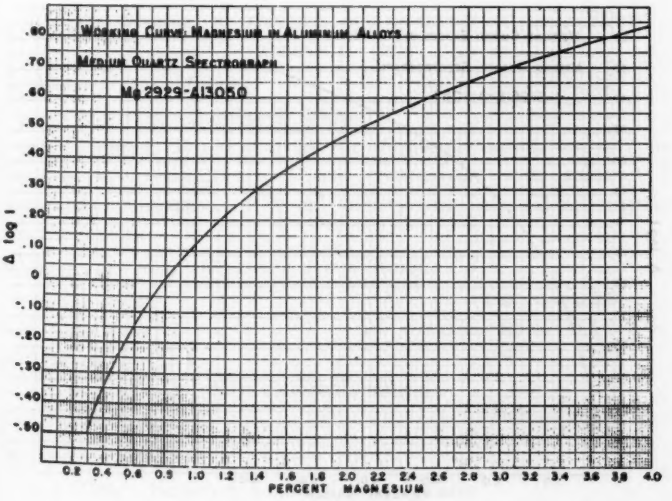
PLATE 1 (b).


Δ log I

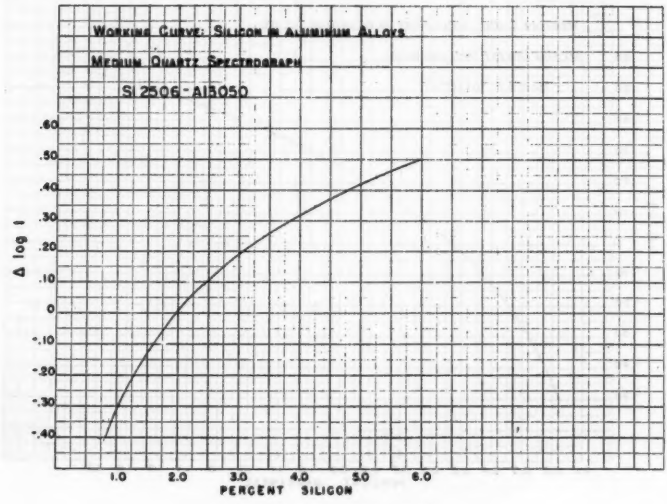
Δ log I



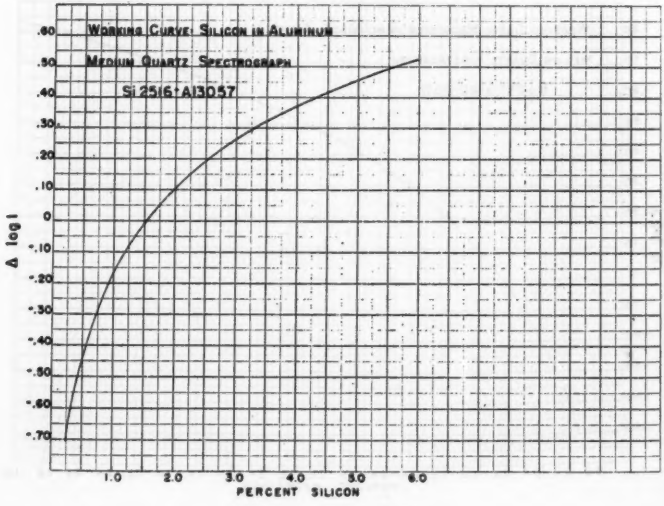
Working Curve No. 2.



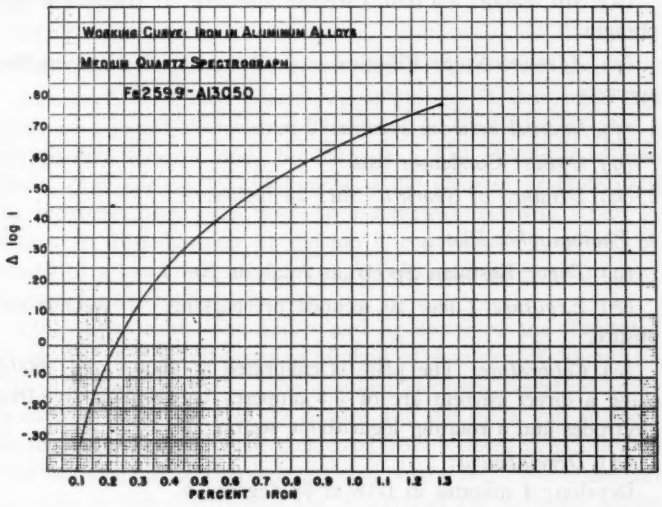
Working Curve No. 3.



WORKING CURVE No. 4.



WORKING CURVE No. 5.



WORKING CURVE No. 6.

10. SPECTROGRAPHIC METHOD OF ANALYSIS OF ALUMINUM ALLOYS II (B).

1. *Material and Method:*

(*a*) *Material:* Aluminum Alloys.

(*b*) *Method:* Rapid analysis for routine determination of conformity to specification. Visual comparison with spectra of standards; comparison of equal density line pairs; densitometric measurements.

2. *Elements to Be Determined and Range:*

Zinc (Zn)	0.05 — 1.3%
Lead (Pb)	0.05 — 0.5%
Bismuth (Bi)	0.05 — 0.5%
Tin (Sn) (in alloys not containing chromium)	0.05 — 0.5%

3. *Spectrograph:*

(*a*) *Type:* Bausch & Lomb Medium Quartz.

(*c*) *Slit width:* 0.025 mm.

(*d*) *Slit length:* 2.5 mm. Circular aperture on Hartmann diaphragm.

(*e*) *Aperture Stop:* Elliptical stop all the way down. Smallest aperture.

(*f*) *Interval between spectra:* 3 mm.

(*g*) *Optics:* Condenser lens.

(*h*) *Distance of Spark to Slit:* 25 inches.

4. *Photographic Plate:*

(*a*) *Type:* Eastman Spectrum Analysis No. 1.

(*b*) *Exposure Time:* 10 seconds presparking. 7 seconds exposure.

(*c*) *Calibration:* The plate is calibrated at 2600A and 3000A using a direct current arc of 3.5 amperes between massive iron electrodes and a rotating logarithmic sector.

(*d*) *Development:*

Develop: 4 minutes in D19 at 68 degrees F.

Fix: 30 seconds in F5.

Wash: 15 minutes in running cold tap water.

5. *Excitation or Source:*

(*a*) *Type:* Bausch and Lomb spark generator.

(*b*) *Adjustment:* Inductance at 100 (20 microhenrys).

6. *Specimens and Standards:*

(*a*) *Preparation of Sample:* The sample used is a solid piece of the aluminum under examination at least one side of which has a flat surface whose minimum dimension is ½ inch. This flat surface is cleaned by polishing the surface using a belt grinder similar to the one used for rough grinding of metallographic specimens. An 80 grit aloxite grinding belt is used.

(*b*) *Standards:* A series of standard aluminum specimens whose compositions vary in such a manner that the range of each element to be determined is covered in a series of about six approximately equal intervals, is used. These standards should be similar in size and shape of specimen to the samples to be analyzed.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: The aluminum specimen under examination.

Lower: A 5/16-inch diameter graphite rod is sharpened to a point in a pencil sharpener. The point is then filed to give a flat surface about 1 mm. in diameter. The electrode is then made ready for use by sparking to a flat piece of graphite until the point has been worn down to a spherical top about 2 mm. in diameter. The diameter of the top is conveniently measured by means of a hand measuring lens. An electrode so prepared may be used for about 25 specimens.

(*b*) *Adjustment:* The fixture and jig described and illustrated in the section " Spectrographic Method of Analysis of Aluminum Alloys II (a) " is used. The graphite electrode described above is inserted in its place in the fixture and the spark gap adjusted by means of the jig. The condenser lens is fixed in position so that the image of the spark is centered on the slit. The aluminum specimen is then placed over the V-notch of the specimen holder arm and the spark is started. The specimen is sparked for 10 seconds with the slit shutter closed and then the shutter is opened and the plate is exposed for 7 seconds. The spark is then stopped. The aluminum specimen is then removed and the gap distance is readjusted by moving the lower graphite electrode up to its proper position as indicated by the jig. The electrode assembly is then ready for another aluminum specimen.

8. *Reference Lines for Elements in Angstrom Units:*

Al: 3060, 2669.
Zn: 2558.
Bi: 3068.
Sn: 2840.
Pb: 2833.

9. *Densitometry:*

(*a*) *Type:* Leeds and Northrup a-c operated recording microphotometer.

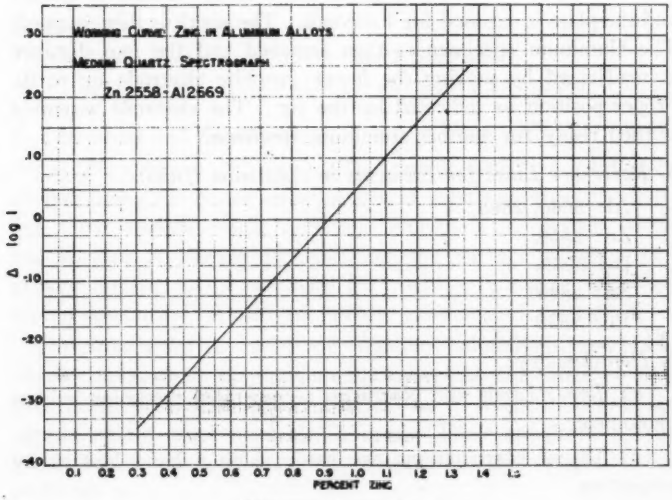
(*b*) Visual examinations are made using a hand lens or by projection.

10. *Analytical Procedure:*

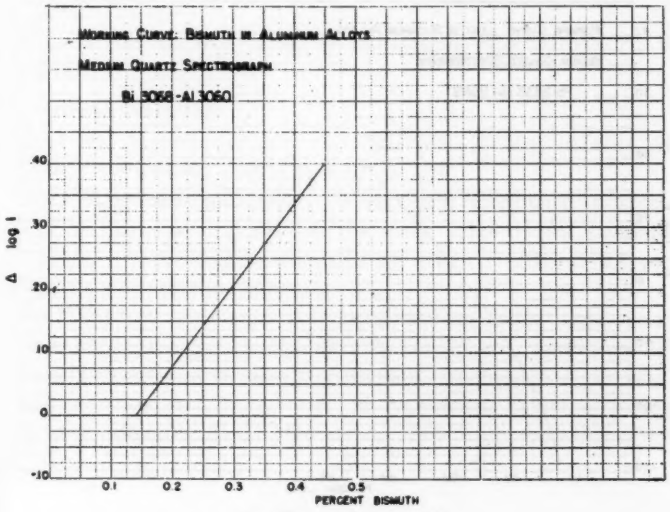
(*a*) *Visual:* Suitable standards are impressed on the plate. A visual comparison of the lines in the spectra of the standard samples and the samples being analyzed is then made.

(*b*) *Equal Density Line Pairs:* The following equal density line pairs are suggested as an aid to rapid visual examination:

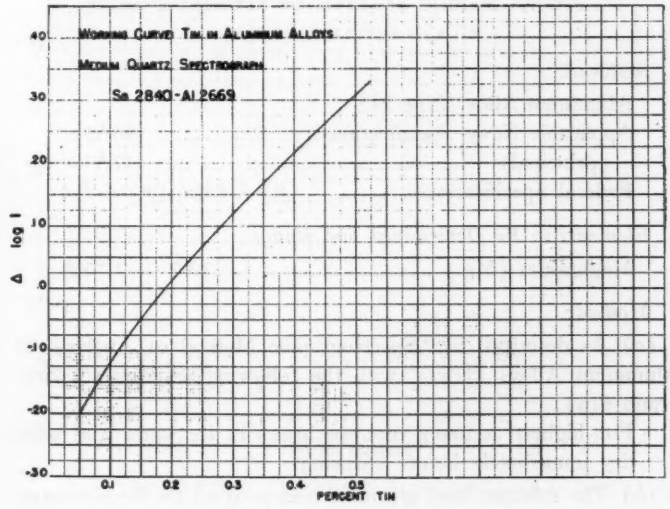
	ZINC	
% Zn	*Zn*	*Al*
0.80	2558	2669
	BISMUTH	
% Bi	*Bi*	*Al*
0.15	3068	3060
	TIN	
% Sn	*Sn*	*Al*
0.20	2840	2669
	LEAD	
% Pb	*Pb*	*Al*
0.30	2833	2669



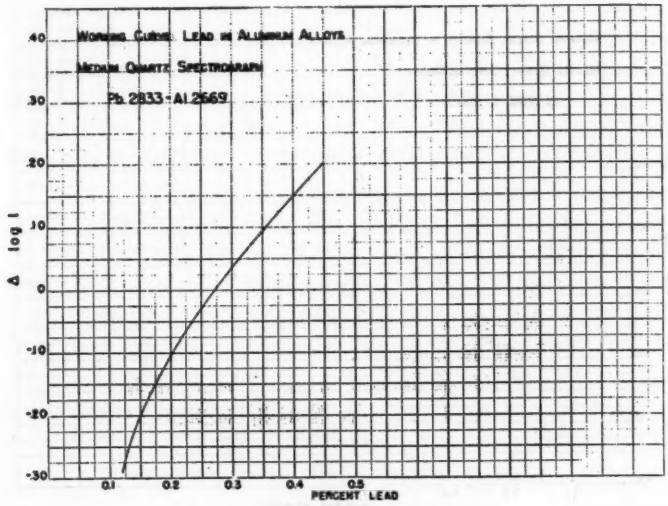
WORKING CURVE NO. 1.



WORKING CURVE NO. 2.



WORKING CURVE NO. 3.



WORKING CURVE No. 4.

11. SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS II(A)—SUPPLEMENT (A).

1. *Material:*

Aluminum Alloy Type 24S
Applicable Navy Specifications..... 46A9e
(principal) 47A10e
Federal Specifications..... QQ-A-355a, QQ-A-354

2. *Elements to Be Determined and Range:*

Magnesium (Mg.) ..... 1.25 — 1.75%

3. *Method:*

(*a*) As described in "Spectrographic Method of Analysis of Aluminum Alloys II(a)" with the following addition to paragraph 6(a):

For highest accuracy cool specimens in ice water and wipe dry immediately before sparking.

(*b*) The relevant lines are to be measured on the densitometer.

4. *Analytical Data:*

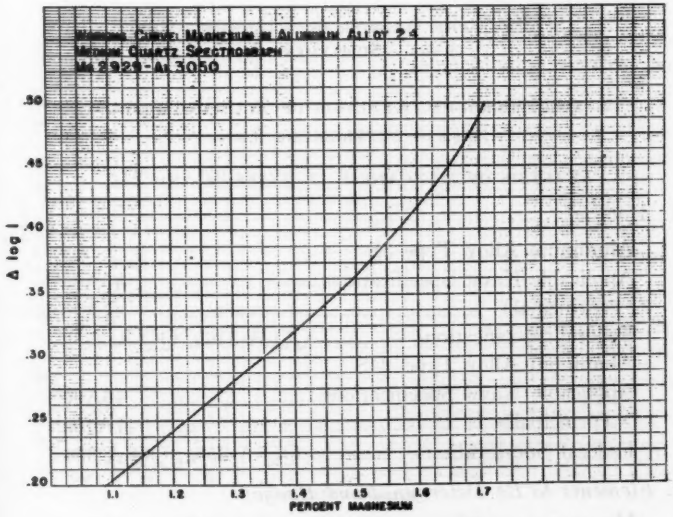
(*a*) A new working curve for this specific alloy and element is attached.

5. *Critical Comment:*

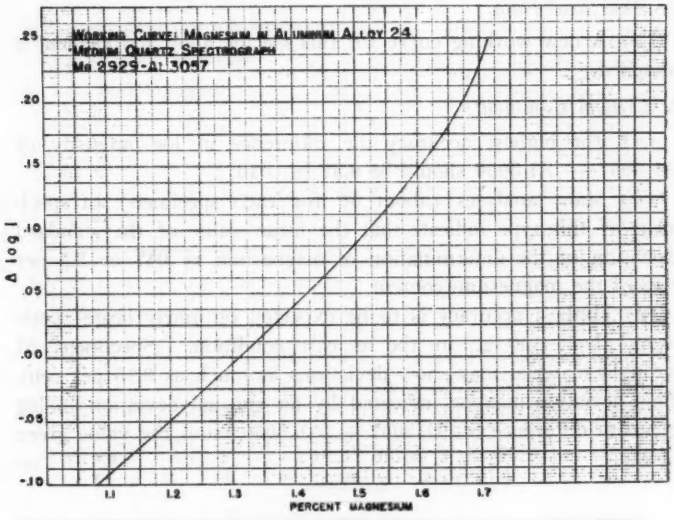
(*a*) For highest accuracy the difference in log intensity of Al 3057 — Al 3050 should be 0.32 ± .010.

(*b*) Many analyses (about 50 for each specimen) of specimens of this type indicate that the mean value of the standard deviation of the determination of magnesium is .047 or 3.5 per cent of the magnesium content.

(*c*) Highest accuracy is to be expected on fairly large specimens, about 100 g., in the as cast condition. Specimens of wrought material may show deviations as much as 0.15 per cent. This deviation may be indicated by an unusual deviation in log intensity difference of Al 3057 — Al 3050 from the value given in 5(a).



SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS
11 (a) —SUPPLEMENT (a).



SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS 11 (a) —SUPPLEMENT (a).

12. SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS II(A)—SUPPLEMENT (B).

ANALYSIS OF MANGANESE IN TYPES 3S AND 24S.

1. *Material:*

Aluminum Alloy Type 3S
Applicable Navy Specifications 46A6e
(principal) 47A4c
Federal Specifications QQ-A-356a, QQ-A-359a
Aluminum Alloy Type 24S
Applicable Navy Specifications 46A9e
(principal) 47A10e
Federal Specifications QQ-A-355a, QQ-A-354

2. *Elements to Be Determined and Range:*

Manganese — 3S ..... 0.90 — 1.40%
24S ..... 0.25 — 0.90%

3. *Method:*

(*a*) As described in "Spectrographic Method of Analysis of Aluminum Alloys II(a)" with the following addition to paragraph 6(a):

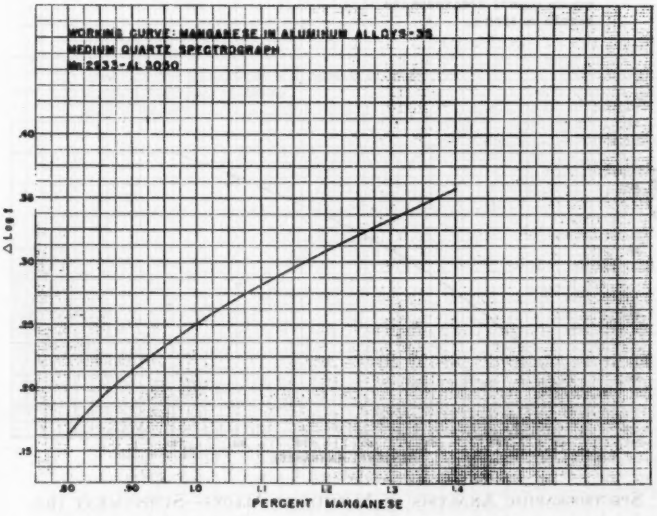
For highest accuracy, with larger specimens, keep the spark 23 inches from the slit.

With smaller pieces, that is those that would normally become hot as a result of the spark excitation keep the spark 22 inches from the slit and cool specimens in ice water and wipe dry immediately before sparking. Use the line pairs Al-3057 and Mn-2933.

(*b*) The relevant lines are to be measured on the densitometer.

4. *Analytical Data:*

(*a*) New working curves for the determination of manganese in 3S and 24S are attached.



SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS—SUPPLEMENT (b). ANALYSIS OF MANGANESE IN 3S AND 24S.

5. *Critical Comment:*

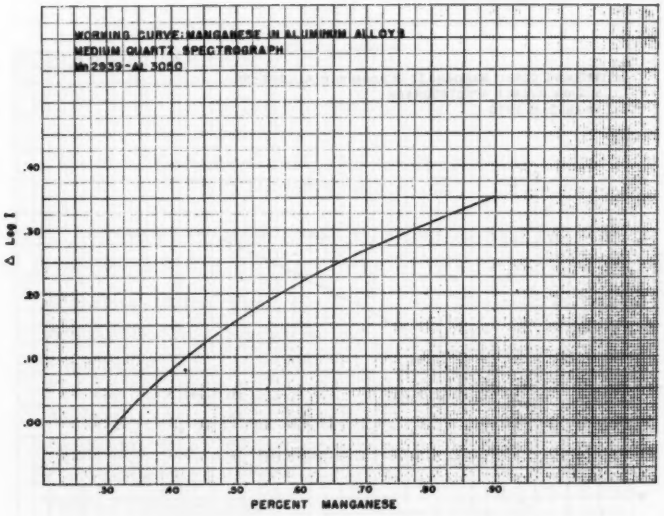
A. *Analysis of 3S.*—Mn. 0.90 — 1.40%.

(*a*) For highest accuracy the difference in log intensity of Al-3057 and Al-3050 should be 0.32 ± .010.

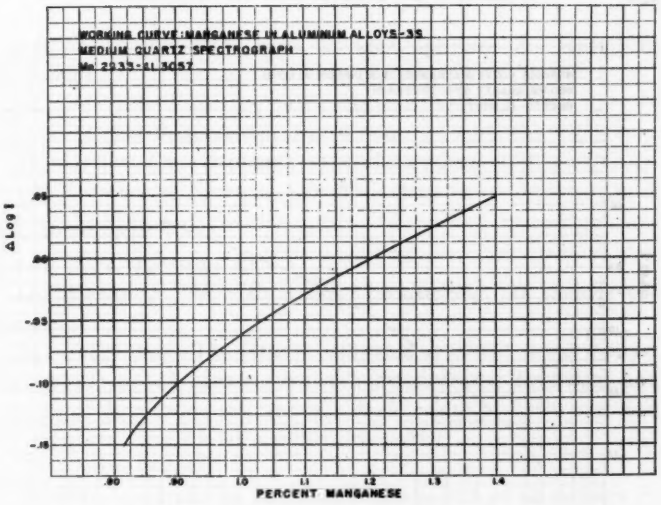
(*b*) Many analyses (about 50 for each specimen) of specimens of this type indicate that the mean value of the standard deviation of the determination of manganese is .040 or 3.5 per cent of the manganese content.

B. *Analysis of 24S.*—Mn. 0.25 — 0.90%.

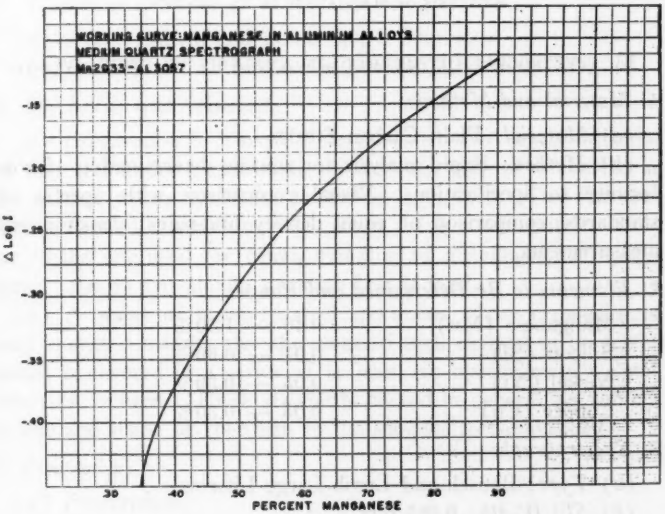
(*a*) Many analyses of specimens of this type indicate that the mean value of the standard deviation of the determination of manganese is .025 or 3.1 per cent of the manganese content.



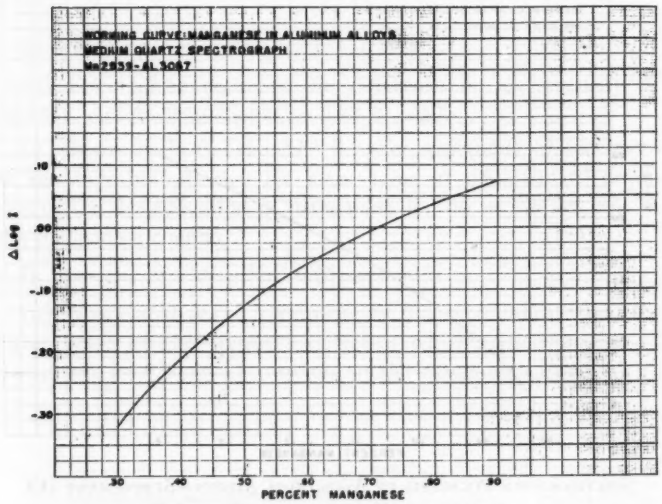
SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS—SUPPLEMENT (b). ANALYSIS OF MANGANESE IN 3S AND 24S.



SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS—SUPPLEMENT (b).
ANALYSIS OF MANGANESE IN 3S AND 24S.



SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS—SUPPLEMENT (b).
ANALYSIS OF MANGANESE IN 3S AND 24S.



SPECTROGRAPHIC ANALYSIS OF ALUMINUM ALLOYS—SUPPLEMENT (b). ANALYSIS OF MANGANESE IN 3S AND 24S.

13. SPECTROGRAPHIC METHOD OF ANALYSIS OF STEEL IV(A).

1. *Material and Method:*

(*a*) *Material:* Plain Carbon Steels.

(*b*) *Method:* Rapid analysis for routine determination of conformity to specification. Visual comparison with spectra of standards; comparison of equal density line-pairs; densitometric measurements.

2. *Elements to Be Determined and Range:*

Manganese (Mn)	0.40 — 1.50%
Silicon (Si)	0.01 — 0.60%
Nickel (Ni)	0.05 — 0.30%
Copper (Cu)	0.05 — 0.30%

3. *Spectrograph:*

(*a*) *Type:* Bausch and Lomb Large Littrow.

(*b*) *Slit Width:* 0.025 mm.

(*c*) *Slit Length:* 2.5 mm. Circular aperture on Hartmann diaphragm.

(*d*) *Aperture Stop:* ⅝ inch; shortest stop.

(*e*) *Interval Between Spectra:* 4 mm.

(*f*) *Optics:* Quartz prism; no condenser lens.

(*g*) *Distance of Spark to Slit:* 25 inches.

4. *Photographic Plate:*

(*a*) *Type:* Eastman 33.

(*b*) *Exposure Time:* 10 seconds presparking, 90 seconds exposure.

(*c*) *Calibration:* The plate is calibrated at 2900A using a direct current arc of 3.5 amperes between massive iron electrodes and a rotating logarithmic step sector. A slit width of 0.020 mm. and an exposure time of 50 seconds are used.

(*d*) *Development:*

Develop: 4 minutes in Eastman Formula D19 at 68 degrees F.

Fix: 10 minutes in Eastman Formula F5.

Wash: 20 minutes in running cold tap water.

5. *Excitation or Source:*

(*a*) *Type:* Bausch and Lomb Spark Generator.

(*b*) *Adjustment:* Inductance in position 4.

6. *Specimens and Standards:*

(*a*) *Preparation of Sample:* The specimen used is a solid piece of the steel under examination at least one side of which has a flat surface whose minimum dimension is ½ inch.. This flat surface is cleaned by polishing the surface using a belt grinder similar to the one used for rough grinding of metallographic specimens. An 80 grit aloxite grinding belt is used.

(*b*) A series of standard steel specimens whose compositions vary in such a manner that the range of each element to be determined is covered in a series of at least six approximately equal intervals, is used. These standards should in general be similar in size and shape of specimen to the samples to be analyzed

7. *Electrodes:*

(*a*) *Preparation:*

Upper: The steel specimen under examination.

Lower: A 5/16-inch diameter graphite rod is sharpened to a point in a pencil sharpener. The point is then filed to give a flat surface about 1 mm. in diameter. The electrode is then made ready for use by sparking to a flat piece of graphite until the point has been worn down to a spherical top about 2 mm. in diameter. The diameter of the top is conveniently measured by means of a hand measuring lens. An electrode so prepared may be used for about 10 specimens.

(*b*) *Adjustment:* The graphite electrode, prepared as described above, is inserted into the fiber holder illustrated in Figure A of the section "Spectrographic Method of Analysis of Aluminum Alloys I". The position of the graphite electrode in the holder is fixed to give the required spark gap by use of a gauge disc similar to the one illustrated in Figure C of the section "Spectrographic Method of Analysis of Aluminum Alloys I". The holder is then mounted in the lower clamp of the spark stand on the spectrograph with the bottom of the fiber block resting on top of the clamp and the under opening turned toward the slit of the spectrograph. The flat surface of the steel specimen, prepared as described above, is then placed on top of the fiber holder. Electrical contact is made by means of a pointed graphite rod which is held in the upper clamp of the spark stand and is brought into contact with the specimen on its upper surface. The electrode combination is then adjusted in vertical and horizontal position so that when the slit is opened wide the image of the spark is centered on the collimating lens which is situated in front of the prism. After an exposure, the upper graphite electrode is raised and the steel specimen is removed. Without changing the position of the fiber holder the gap distance is readjusted by moving the lower graphite electrode up to its proper position as indicated by the gauge disc. The electrode assembly is then ready for another steel specimen.

8. *Reference Lines for Elements in Angstrom Units:*

Fe: 3413, 3287, 2912, 2903
Mn: 3483, 2890, 2887
Si: 2882
Ni: 3415
Cu: 3274

9. *Densitometry:*

(*a*) *Type:* Leeds and Northrup a-c. operated recording microphotometer.

(*b*) Visual examinations are made using a hand lens or by projection.

10. *Analytical Procedure:*

(*a*) *Visual:* Spectra of suitable standards are impressed on the plate. A visual comparison of the lines in the spectra of the standard samples and the samples being analyzed is then made.

(*b*) *Equal Density Line Pairs:* The following equal density line pairs are suggested as an aid to rapid visual examination:

MANGANESE

% Mn	*Mn*	*Fe*
0.40	2890	2912
1.0	2887	2912

SILICON

% Si	*Si*	*Fe*
0.25	2882	2903
0.50	2882	2912

NICKEL

% Ni	*Ni*	*Fe*
above 0.25	3415	3413

COPPER

% Cu	*Cu*	*Fe*
0.25	3274	3287

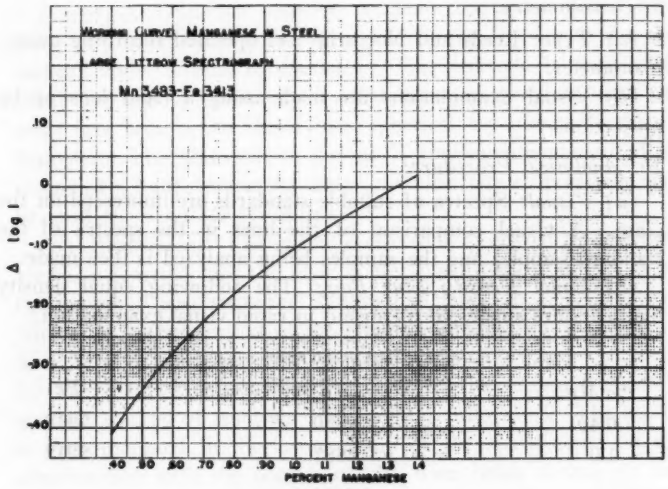
(*c*) *Densitometric Readings and Working Curves:* Working curves are obtained by plotting the difference in the logarithm of intensities against per cent element to be determined using the following lines:

MANGANESE.

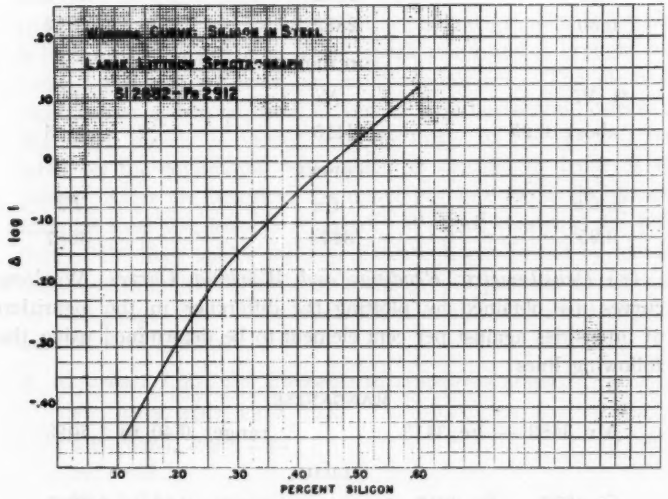
Mn 3483 — Fe 3413 range: 0.40 to 1.50%

SILICON

Si 2882 — Fe 2912 range: 0.01 to 0.60%



Working Curve No. 1.



Working Curve No. 2.

14. SPECTROGRAPHIC METHOD OF ANALYSIS OF STEEL IV (B).

1. *Material and Method:*

(*a*) *Material:* Plain carbon and low alloy steels.

(*b*) *Method:* Rapid analysis for routine determination of conformity to specification. Visual comparison with spectra of standards; comparison of equal density line-pairs; densitometric measurements.

2. *Elements to Be Determined and Range:*

Molybdenum (Mo)	0.05 — 0.30%
Chromium (Cr)	0.05 — 0.30%
Vanadium (V)	0.01 — 0.20%

3. *Spectrograph:*

(*a*) *Type:* Bausch and Lomb Large Littrow.

(*b*) *Slit Width:* 0.025 mm.

(*c*) *Slit Length:* 2.5 mm. Circular aperture on Hartmann diaphragm.

(*d*) *Aperture Stop:* 5/8 inch; shortest stop.

(*e*) *Interval Between Spectra:* 4 mm.

(*f*) *Optics:* Quartz prism; no condenser lens.

(*g*) *Distance of Spark to Slit:* 25 inches.

4. *Photographic Plate:*

(*a*) *Type:* Eastman 33.

(*b*) *Exposure Time:* 10 seconds presparking, 90 seconds exposure.

(*c*) *Calibration:* The plate is calibrated at 2900A using a direct current arc of 3.5 amperes between massive iron electrodes and a rotating logarithmic step sector. A slit width of 0.020 mm. and an exposure time of 50 seconds are used.

(*d*) *Development:*

Develop: 4 minutes in Eastman Formula D19 at 68 degrees F.
Fix: 10 minutes in Eastman Formula F5.
Wash: 20 minutes in running cold tap water.

5. *Excitation or Source:*

(*a*) *Type:* Bausch and Lomb Spark Generator.

(*b*) *Adjustment:* Inductance in position 4.

6. *Specimens and Standards:*

(*a*) *Preparation of Sample:* The specimen used is a solid piece of steel under examination at least one side of which has a flat surface whose minimum dimension is ½ inch. This flat surface is cleaned by polishing the surface using a belt grinder similar to the one used for rough grinding of metallographic specimens. An 80 grit aloxite belt is used.

(*b*) *Standards:* A series of standard steel specimens whose compositions vary in such a manner that the range of each element to be determined is covered in a series of about five approximately equal intervals is used. These standards should be similar in size and shape of specimen to the samples to be analyzed.

7. *Electrodes:*

(*a*) *Preparation:*

Upper: The steel specimen under examination.

Lower: A 5/16-inch diameter graphite rod is sharpened to a point in a pencil sharpener. The point is then filed to give a flat surface about 1 mm. in diameter. The electrode is then made ready for use by sparking to a flat piece of graphite until the point has been worn down to a spherical top about 2 mm. in diameter. The diameter of the top is conveniently measured by means of a hand measuring lens. An electrode so prepared may be used for about 10 specimens.

(*b*) *Adjustment:* The graphite electrode prepared as described above is inserted into the fiber holder illustrated in Figure A of the section "Spectrographic Method of Analysis of Aluminum Alloys I." The position of the graphite electrode in the holder is fixed to give the required spark gap by use of a gauge disc similar to the one illustrated in Figure C of the section "Spectrographic Method of Analysis of Aluminum Alloys I." The holder is then mounted in the lower clamp of the spark stand on the spectrograph with the bottom of the fiber block resting on top of the clamp and the under opening turned toward the slit of the spectrograph. The flat surface of the steel specimen, prepared as described above, is then placed on top of the fiber holder. Electrical contact is made by means of a pointed graphite rod which is held in the upper clamp of the spark stand and is

brought into contact with the steel specimen on its upper surface. The electrode combination is then adjusted in vertical and horizontal position so that when the slit is opened wide the image of the spark is centered on the collimating lens which is situated in front of the prism. After an exposure, the upper graphite electrode is raised and the steel specimen is removed. Without changing the position of the fiber holder the gap distance is readjusted by moving the lower graphite electrode up to its proper position as indicated by the gauge disc. The electrode assembly is then ready for another steel specimen.

8. *Reference Lines in Angstrom Units:*

Fe: 2912, 2776
Mo: 2775
Cr: 2863
V: 2909

9. *Densitometry:*

(*a*) *Type:* Leeds and Northrup a-c operated recording microphotometer.

(*b*) Visual examinations are made using a hand lens or by projection.

10. *Analytical Procedure:*

(*a*) *Visual:* Spectra of suitable standards are impressed on the plate. A visual comparison of the lines in the spectra of the standard samples and the samples being analyzed is then made.

(*b*) *Equal Density Line Pairs:* The following equal density line pairs are suggested as an aid to rapid visual examination:

MOLYBDENUM

% Mo	*Mo*	*Fe*
0.30	2775	2776

CHROMIUM

% Cr	*Cr*	*Fe*
0.30	2863	2912

VANADIUM

% V	*V*	*Fe*
0.15	2909	2912

(*c*) *Densitometric Readings and Working Curves:* Working curves are obtained by plotting the difference in the logarithm of intensities against per cent element to be determined using the following lines:

MOLYBDENUM

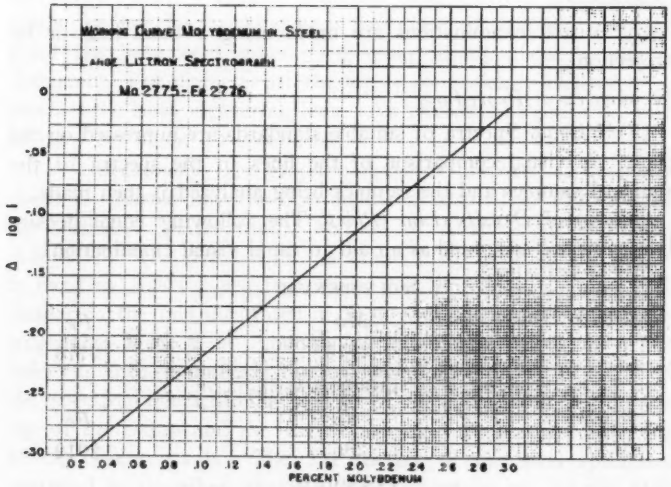
Mo 2775 — Fe 2776 range: 0.05 — 0.30%

CHROMIUM

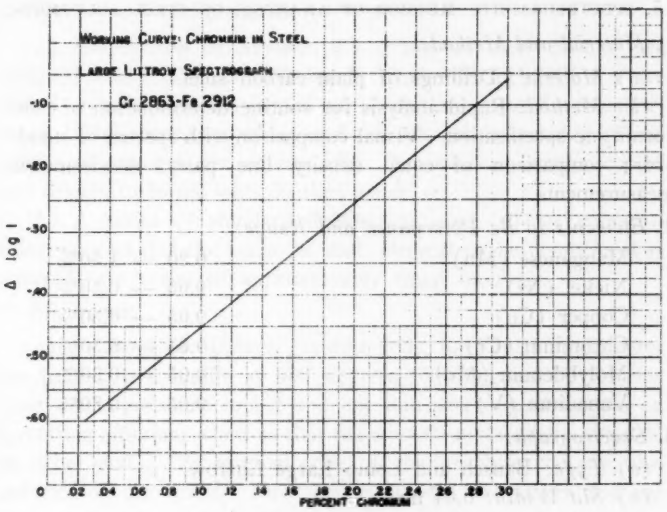
Cr 2863 — Fe 2912 range: 0.05 — 0.30%

VANADIUM

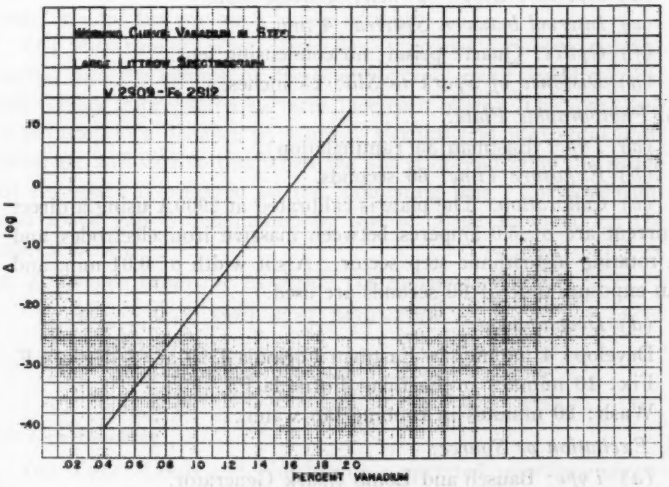
V 2909 — Fe 2912 range: 0.01 — 0.20%



Working Curve No. 1.



WORKING CURVE NO. 2.



WORKING CURVE NO. 3.

15. SPECTROGRAPHIC METHOD OF ANALYSIS OF STEEL SOLUTIONS.

1. *Material and Method:*

(*a*) *Material*: Drillings of plain carbon steel.

(*b*) *Method:* Rapid analysis for routine determination of conformity to specification. Visual comparison with spectra of standards; comparison of equal density line pairs; densitometric measurements.

2. *Elements to Be Determined and Range:*

Manganese (Mn)	0.20 — 1.50%
Nickel (Ni)	0.05 — 0.50%
Copper (Cu)	0.05 — 0.30%
Chromium (Cr)	0.05 — 0.30%
Molybdenum (Mo)	0.05 — 0.30%
Vanadium (V)	0.05 — 0.30%

3. *Spectrograph:*

(*a*) *Type:* Bausch and Lomb Large Littrow.

(*b*) *Slit Width:* 0.04 mm.

(*c*) *Slit Length:* 2.5 mm. Circular aperture on Hartmann diaphragm.

(*d*) *Aperture Stop:* 5/8 inch; shortest stop.

(*e*) *Interval between Spectra:* 4 mm.

(*f*) *Optics:* Quartz prism; no condensing lens.

(*g*) *Distance of Spark to Slit:* 25 inches.

4. *Photographic Plate:*

(*a*) *Type:* Eastman 33 (antihalation).

(*b*) *Exposure Time:* 60 seconds.

(*c*) *Calibration:* The plate is calibrated at 2900A using a direct current arc of 5.0 amperes between massive iron electrodes and a rotating logarithmic step sector. A slit width of 0.01 mm. and an exposure time of 60 seconds are used.

(*d*) *Development:*

Develop: 4 minutes in Eastman Formula D19 at 68 degrees F.

Fix: 10 minutes in Eastman Formula F5.

Wash: 20 minutes in running tap water.

5. *Excitation or Source:*

(*a*) *Type:* Bausch and Lomb Spark Generator.

(*b*) *Adjustment:* Inductance in position 2.

6. *Specimens and Standards:*

(*a*) *Preparation of Sample:* 2.5 grams of steel drilling are weighed into a 250 ml. Erlenmeyer flask; 40 ml. HCl 1:1 are added and the contents heated until solution is nearly complete. 5 ml. HNO_3 conc. are added and the solution is boiled until the oxides of nitrogen are driven off. The solution is then cooled and diluted to 50 ml. with distilled water.

(*b*) A series of standard drillings is used. Their compositions vary so that the range of each element to be determined is covered in a series of approximately equal intervals.

7. *Electrodes:*

(*a*) *Preparation:* 12-inch graphite rods, 5/16 inch in diameter are heated in a muffle at 900 degrees-1000 degrees F. for one hour. The rods are cooled and cut into seven equal lengths on a rotating alundum wheel so that flat smooth surfaces are obtained at either end. The original ends of the graphite rod are also polished on the wheel. Two such electrodes, one upper and one lower, are each impregnated at either end with one drop of solution, prepared as above from a pipette. The electrodes are sparked immediately after absorption is complete. Each electrode may be used for two such impregnations.

(*b*) *Adjustment:* Two electrodes, prepared as above, are inserted into the clamps of the spectrograph spark stand so that the freshly impregnated surfaces face each other. The spark gap is adjusted to a distance of 4 mm. Vertical and horizontal positions are adjusted so that when the slit is opened wide the image of the spark is centered on the collimating lens. Correct height and spark gap is maintained by use of a bar mounted on the optical bench.

8. *Reference Lines for Elements (in Angstrom Units):*

Fe: 2912, 2929, 3287, 3413, 2776

Mn: 2933	Cr: 2863
Ni: 3415, 3051	V: 2909
Cu: 3274	Mo: 2775

9. *Densitometry:*

(*a*) *Type:* Leeds and Northrup a-c operated recording microphotometer.

(*b*) Visual examinations are made by use of a hand lens.

10. *Analytical Procedure:*

(*a*) *Visual:* Spectra of suitable standards are impressed on the plate. A visual comparison of the lines in the spectra of the standards and the samples being analyzed is then made.

(*b*) *Equal Density Line Pairs:* The following equal density line pairs are suggested as an aid to rapid visual examination:

MANGANESE

% Mn	*Mn*	*Fe*
0.30	2933	2912
0.40	2933	2929

MOLYBDENUM

% Mo	*Mo*	*Fe*
0.25	2775	2776

VANADIUM

% V	*V*	*Fe*
0.22	2909	2912

NICKEL

% Ni	*Ni*	*Fe*
Above 0.25	3415	3413

COPPER

% Cu	*Cu*	*Fe*
0.25	3274	3287

(*c*) *Densitometric Readings and Working Curves:* Working curves are obtained by plotting the difference in the logarithm of intensities against per cent element to be determined using the following lines:

MANGANESE

Mn 2933 — Fe 2912 range: 0.20 — 1.50%

CHROMIUM

Cr 2863 — Fe 2912 range: 0.05 — 0.30%

NICKEL

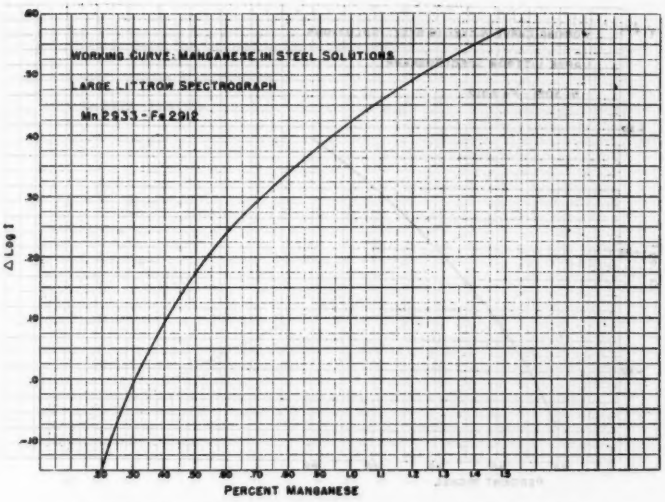
Ni 3051 — Fe 2912 range: 0.20 to 0.50%

VANADIUM

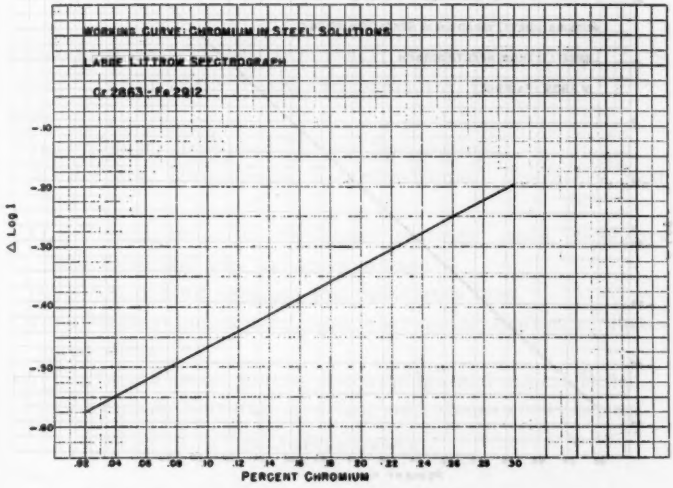
V 2909 — Fe 2912 range: 0.05 — 0.30%

MOLYBDENUM

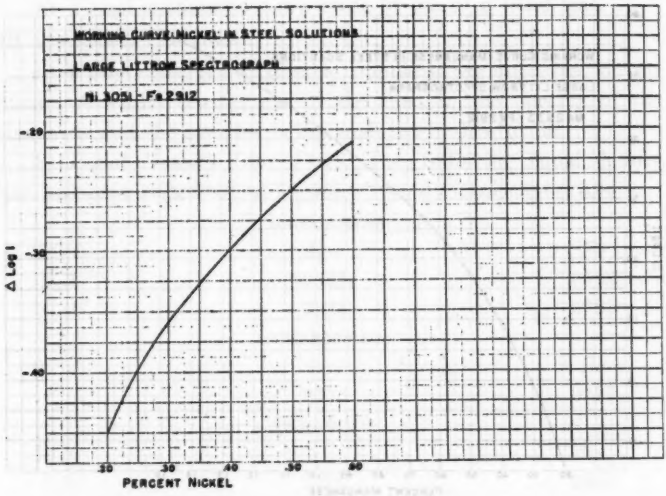
Mo 2775 — Fe 2776 range: 0.05 — 0.30%



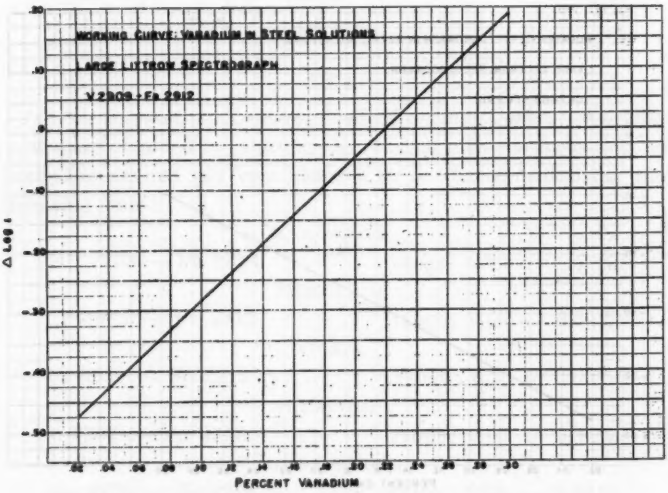
SPECTROGRAPHIC METHOD OF ANALYSIS OF STEEL SOLUTIONS.



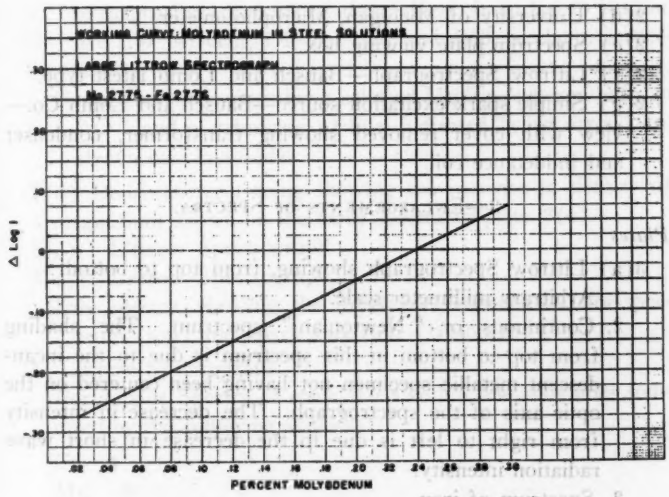
SPECTROGRAPHIC METHOD OF ANALYSIS OF STEEL SOLUTIONS.



SPECTROGRAPHIC METHOD OF ANALYSIS OF STEEL SOLUTIONS.



SPECTROGRAPHIC METHOD OF ANALYSIS OF STEEL SOLUTIONS.



SPECTROGRAPHIC METHOD OF ANALYSIS OF STEEL SOLUTIONS.

CHAPTER X.

1—PLATES.

INSTALLATIONS AT THE INDUSTRIAL TEST LABORATORY U. S. NAVY YARD, PHILADELPHIA, PA.

Plates

1(a) Control panel and Littrow Spectrograph.

1(b) Spark Transformer, arc transformer, emergency push button.

1(c) Interrupter disc, condenser switches, main secondary switch, control gap for spark voltage.

1(d) Arc resistor switches, and inductance taps.

1(e) Medium quartz spectrograph set up for analysis of aluminum alloys.

1(f) Baird 3 meter grating spectrograph and optical Bench.

1(g) Leeds & Northrup recording microdensitometer set up.

2—INSTRUMENTS.

Plates

2(a), 2(b) and 2(c) Views of Leeds & Northrup Microdensitometer.

4(d) Densitometer tracings of the indicated manganese and reference iron line showing how the densitometer indicates progressive increase in relative density of the manganese line in plate 4(c).

4(e) Nickel and vanadium lines indicated.

4(f) Nickel and chromium lines indicated.

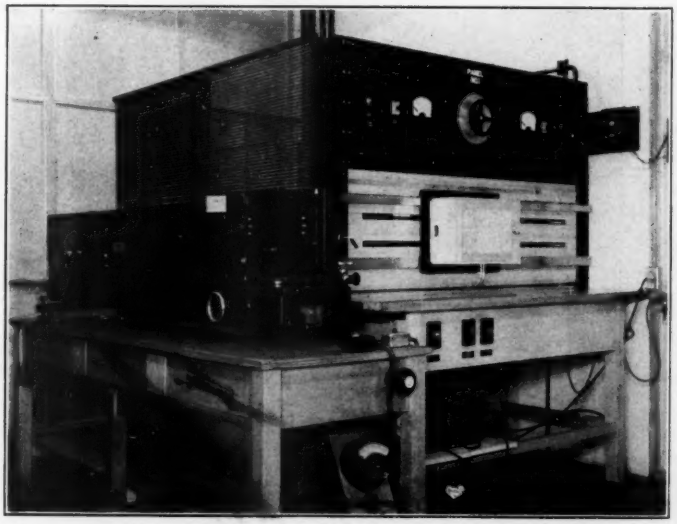


PLATE I (a).

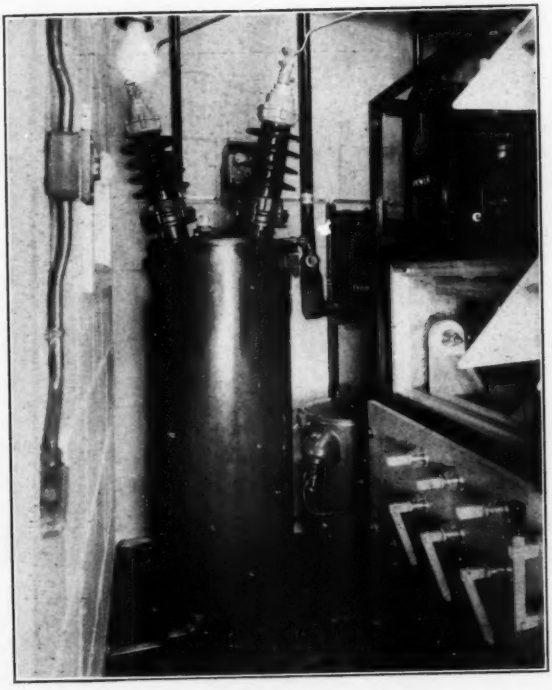


PLATE I (b).

PLATE 1 (c).

PLATE 1 (d).

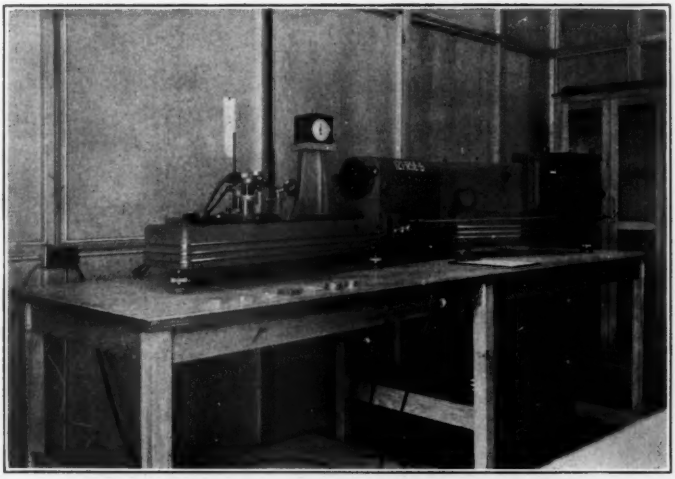


PLATE 1 (e).

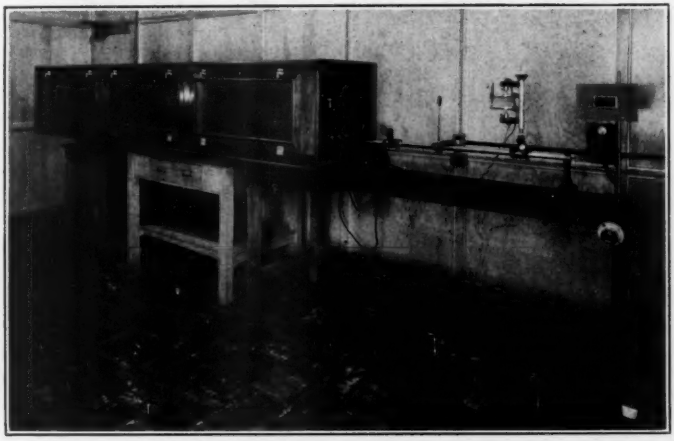


PLATE 1 (f).

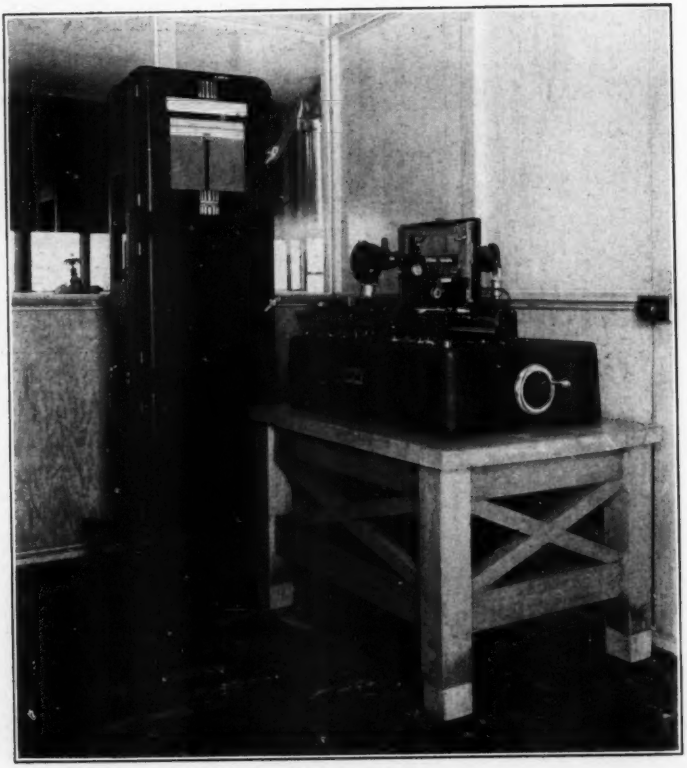


PLATE 1 (g).

PLATE 2 (a).

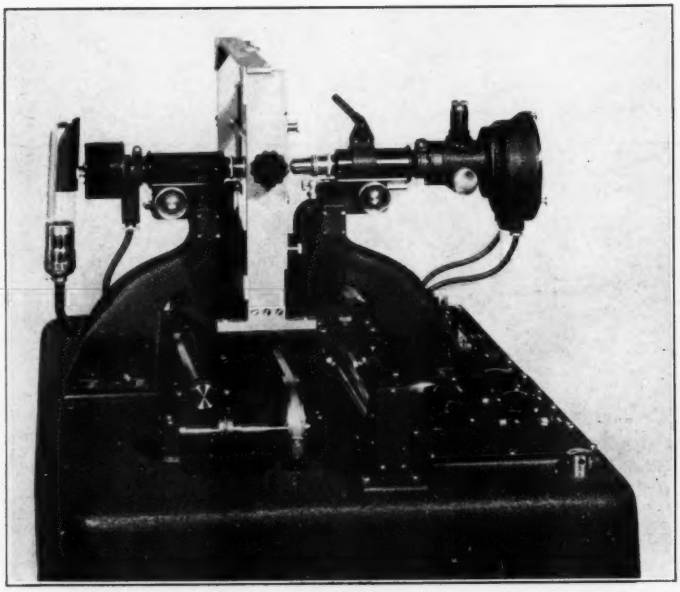


PLATE 2 (b).

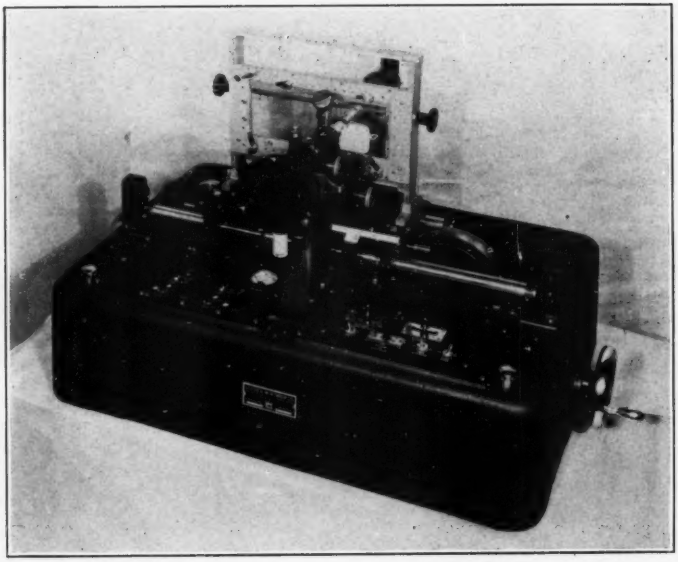


PLATE 2 (c).

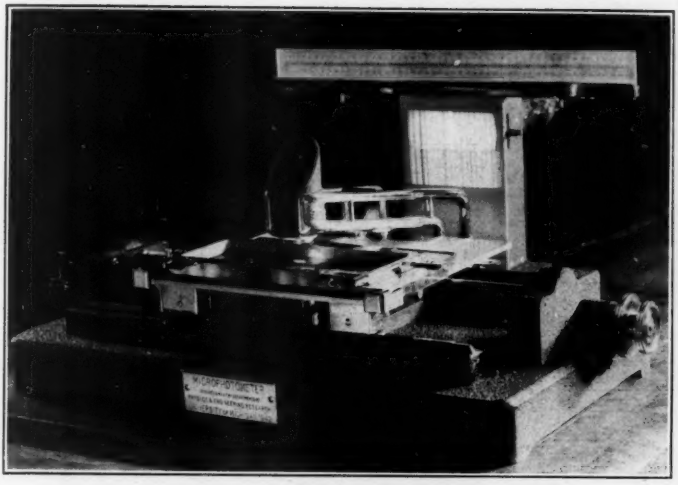


PLATE 2 (d).

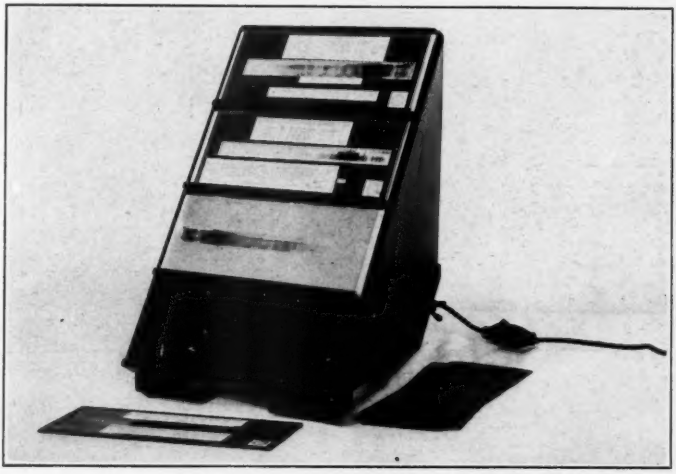


PLATE 2 (e).

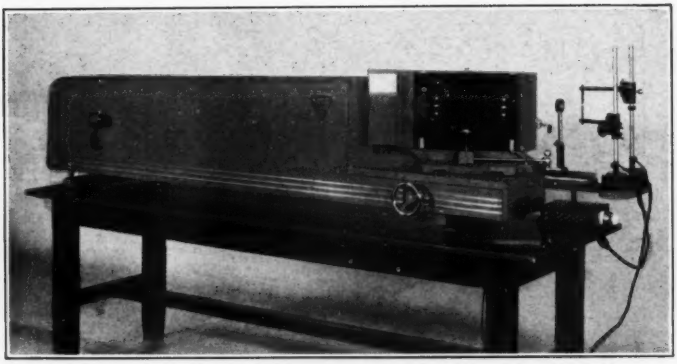


PLATE 2 (f).

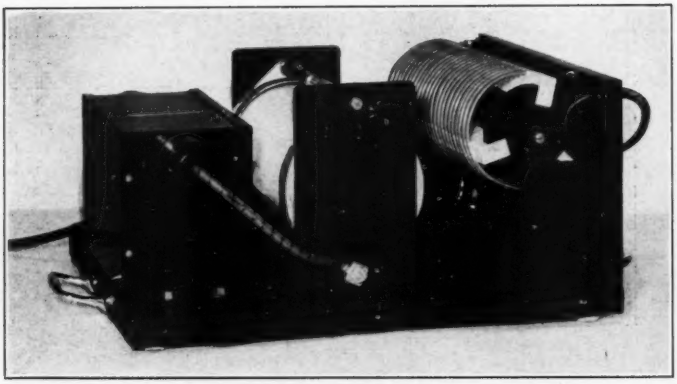


PLATE 2 (g).

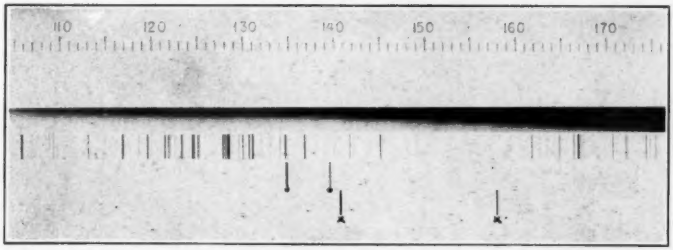


PLATE 3 (a).

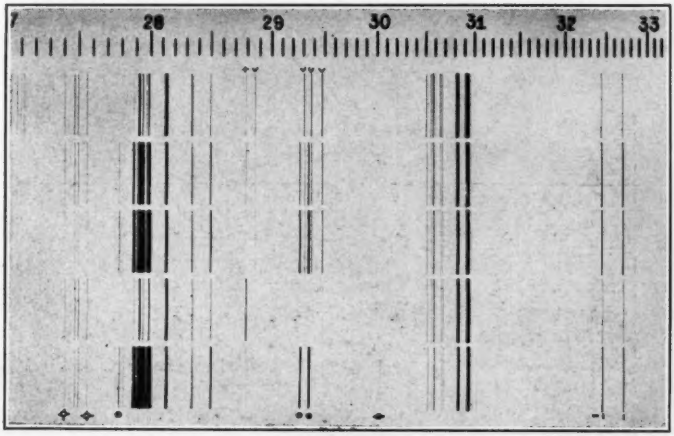


PLATE 3 (b).

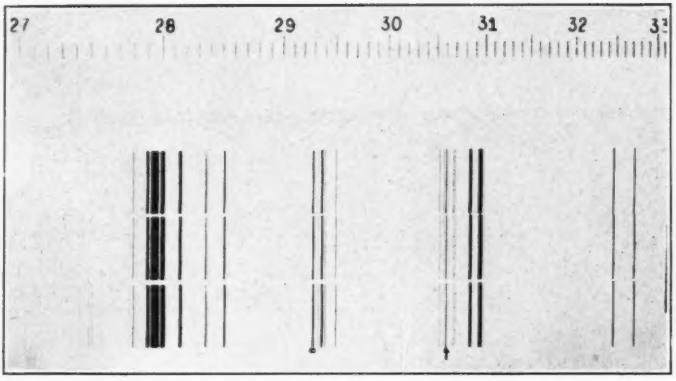


PLATE 3 (c).

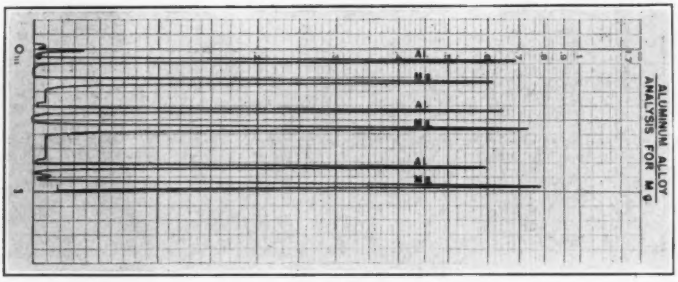


PLATE 3 (d).

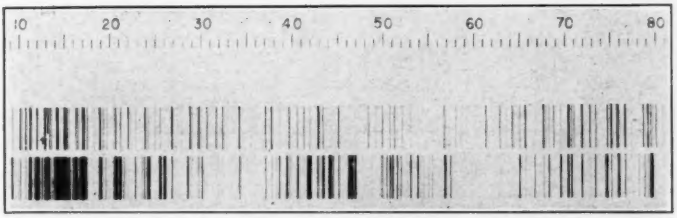


PLATE 3 (e)-1.

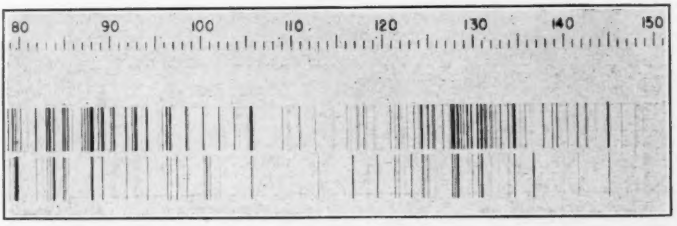


PLATE 3 (e)-2.

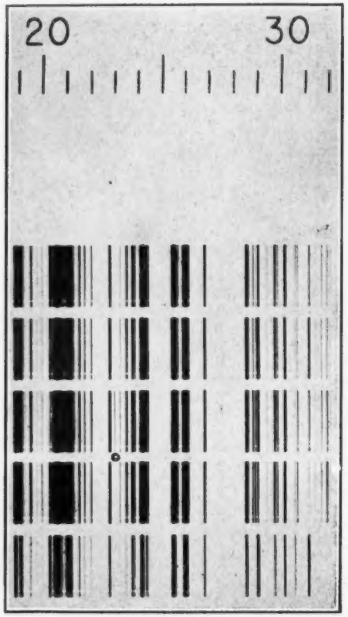


PLATE 4 (a).

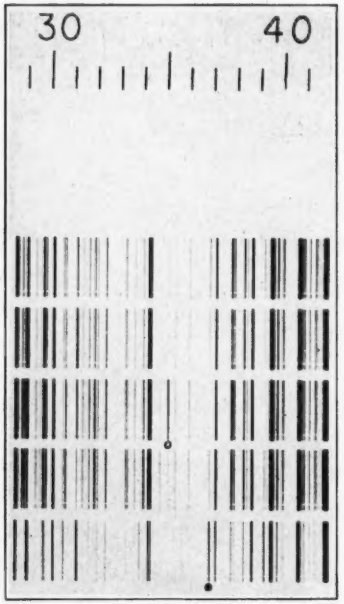


PLATE 4 (b).

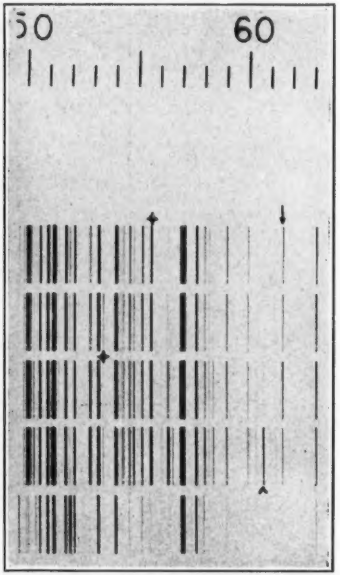


PLATE 4 (c).

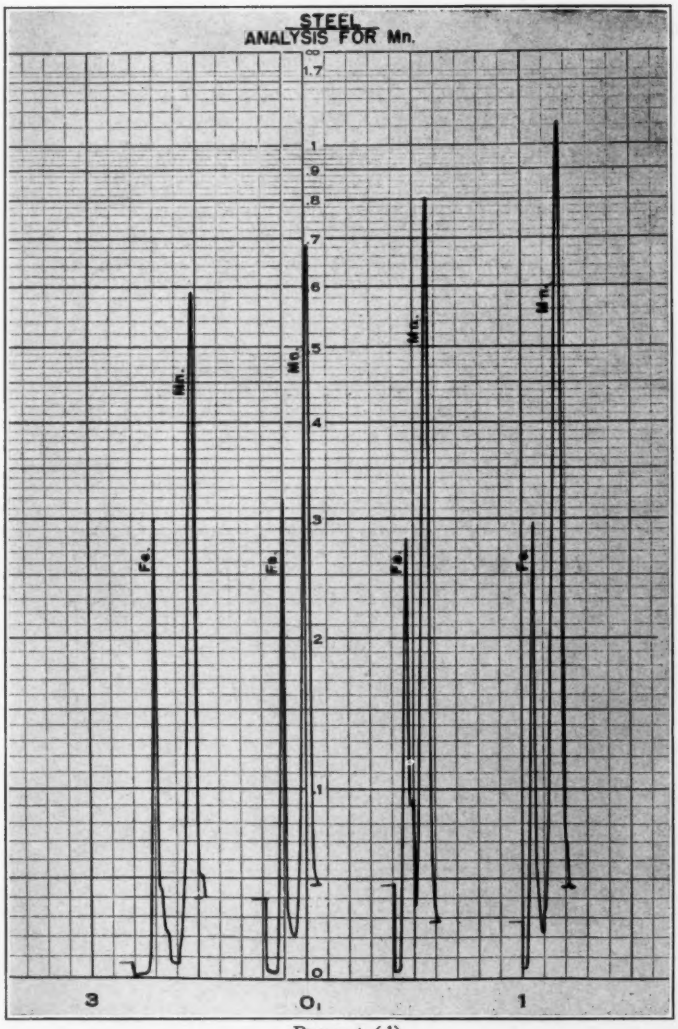

STEEL
ANALYSIS FOR Mn.
∞
1.7
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Mn.
Mn.
Mn.
Mn.
Fe.
Fe.
Fe.
Fe.
3
O₁
1

PLATE 4 (d).

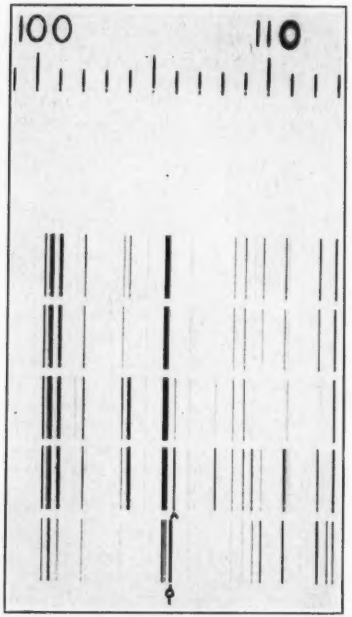


PLATE 4 (c).

PLATE 4 (f).

Bibliography.

Principles of Optics—Hardy & Perrin—McGraw-Hill.

Measurement of Radiant Energy—W. E. Forsythe—McGraw-Hill.

Principles of Electricity—Page & Adams—D. VanNostrand.

Physics of the Developed Photographic Image—F. E. Ross—Eastman Kodak Company.

Chemical Spectrography—Brode—John Wiley & Sons.

The Spectrochemical Analysis of Metals and Alloys—F. Twyman—Chemical Publishing Company.

Index to the Literature on Spectrochemical Analysis 1920-1939—American Society for Testing Materials.

Proceedings of Summer Conferences on Spectroscopy and Its Applications—1937-1938-1939—John Wiley & Sons.

Subsequent Conferences Published in The Journal of American Optical Society—Wavelength Tables—Harrison—John Wiley & Sons.

Periodicals.

Journal of the American Optical Society.

Industrial & Engineering Chemistry, Analytical Edition.

Various Literature Issued by Manufacturers of Equipment:

Bausch & Lomb Optical Company—Rochester, N. Y.

Baird Associates—Cambridge, Mass.

Dietert, H. W., Company—Detroit, Michigan.

Eastman Kodak Company—Rochester, N. Y.

Gaertner Scientific Corporation—Chicago, Ill.

Hilger Company, Ltd.—London, England.

Leeds & Northrup Company—Philadelphia, Pa.

Particular acknowledgment is paid to the papers by Kayser, Sawyer, and Vincent as published in the Proceedings of the Summer Conferences.

" Spectrographic Analysis of Certain Materials ", etc.—Sherman-Jeffries, J. A. S. N. E. 50 (February, 1938), pp. 39 to 51.

ALIGNMENT OF SHAFTING BY THE WIRE SAG METHOD.

By Grover C. Bayles.*

Introduction.

Every shipbuilder retains in his own mind and employs in practice such installation methods as will insure proper final alignment of main propulsion shafting, based on locally established procedures for setting up a strut and stern tube boring line and installing the shafting. The resultant variety of methods have been prosecuted, each in its own definite pattern, to satisfactory conclusions and shaft alignment troubles are things of the past. The procedure as outlined herein is presented, not with the intent of discrediting other methods of shaft line establishment, but to give, rather, the steps of the development and the application of the wire sag method by the Philadelphia Navy Yard and a few highlights of installation and alignment methods employed in that Yard.

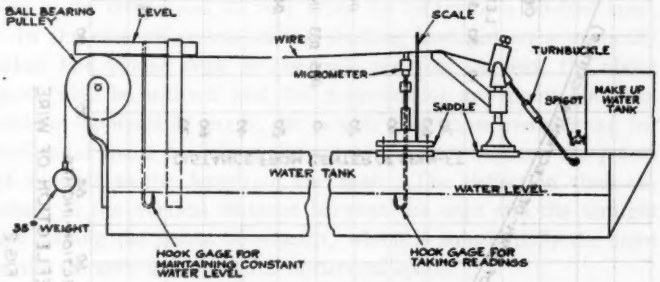
Historical Background of Sag Method.

In 1912, the Navy Yard, with the intention of adopting the wire sag method for establishment of shaft lines, performed its first experiments to determine the sag, in form and amount, of a wire supported at both ends, using the apparatus shown in Figure 1 and taking data of spans from 10 to 150 feet at 10 foot intervals.

The experiment was performed with steel music wire, 0.020 inch in diameter, having a breaking strength of 105 pounds and a tensile strength of 330,000 p.s.i., the latter figures determined from test. The wire was secured at one end and led over a ball bearing sheave at the other, with a 35 pound weight attached to insure

* Marine Engineer of Industrial Department, Navy Yard, Philadelphia, Pa.

constant tension. (See Figure 1.) The points of support were at the same level and the distances between the surface of the water and the supports were observed. The water level was maintained as nearly constant as possible by adding water at intervals between measurements to make up loss due to evaporation. The room temperature was very nearly constant throughout the experiments. Sag, or deflections, were measured by means of a hook gauge and micrometer.



APPARATUS FOR MEASURING WIRE DEFLECTIONS

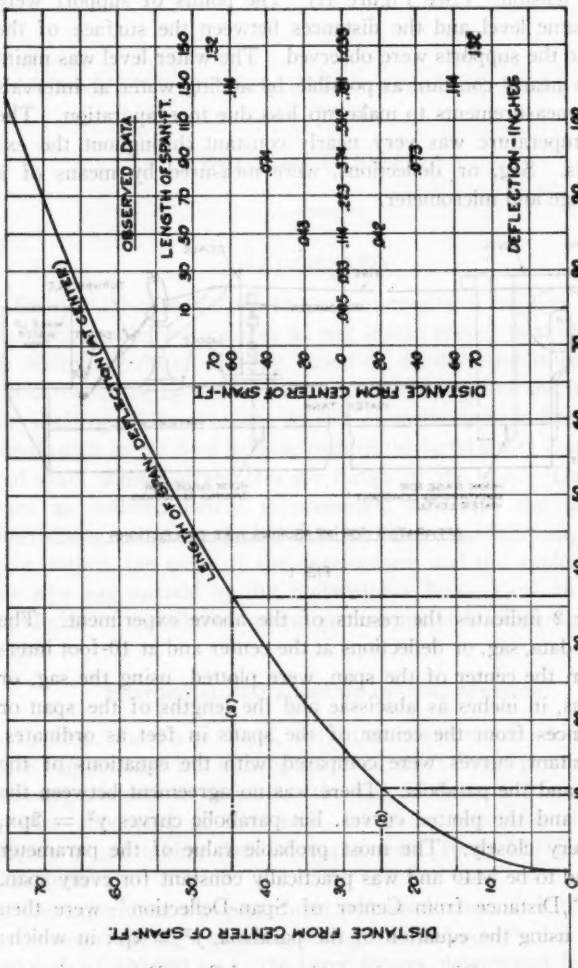
FIG. 1

Figure 2 indicates the results of the above experiment. The observed data, sag, or deflections at the center and at 10-foot intervals from the center of the span, were plotted, using the sag, or deflections, in inches as abscissae and the lengths of the span or the distances from the center of the spans in feet as ordinates. The resultant curves were compared with the equations of the catenary and the parabola. There was no agreement between the catenary and the plotted curves, but parabolic curves $y^2 = 2px$, agreed very closely. The most probable value of the parameter was found to be 5440 and was practically constant for every span. Curves, "Distance from Center of Span-Deflection" were then replotted using the equation of the parabola, $y^2 = 2px$ in which:

y = Distance from Center of Span-Feet

x = Deflection—Inches

$2p = 5440$



CURVE OF DEFLECTION OF WIRE

FIG. 2

In order to provide a means of determining deflections for spans other than those used in the experiment, a series of curves, "Length of Span-Deflection", were plotted from the above curves, using the same parabolic equation; $y^2 = 5440x$. Figure 2 shows a few of the observations and the resultant master curve, "Length of Span-Deflection (At Center)". From this curve, the deflection at the center of any span up to 150 feet is read direct and the deflection at any point removed from the center of the span determined by (a-b), which, for illustration purposes, gives the deflection at the center and 25 feet from the center of a 90-foot span.

In the case of vessels having shafting installed on a vertically raked line whose slope is one inch per foot or less, the above curve may be utilized and the deflection at any point obtained, without appreciable error, in exactly the same manner as for horizontal spans by taking the actual distance between the points of support as the length of the span. The deflection thus obtained is the vertical distance between the wire and the straight line joining the points of support, which is substantially the same as the distance measured for horizontal spans.

FIG. 2

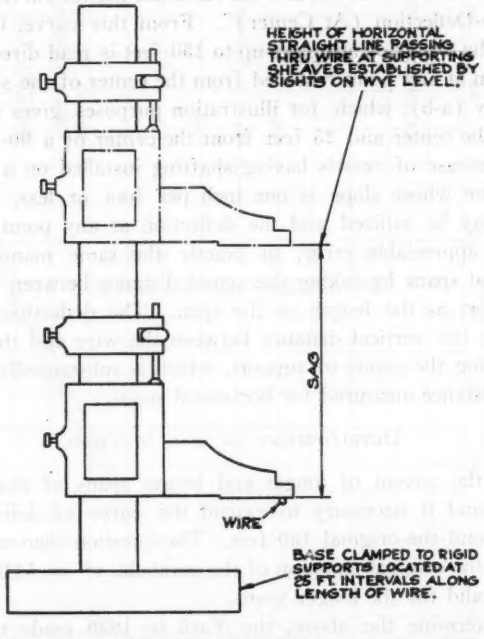
Development of Sag Method.

With the advent of longer and longer spans of shafting, the Yard found it necessary to extend the curve of deflections of wire beyond the original 150 feet. The question then arose as to whether the original equation of the parabola, $y^2 = 5440x$, would still be valid for the longer spans.

To determine the above, the Yard in 1939 made tests of a 300-foot span, using the same diameter wire and supporting it in the same manner as in the original experiment. A sag gauge (Figure 3) and a Wye Level (36 Power) were used to take readings. The ends of the wire were adjusted and secured in a true horizontal plane by means of sights through the Wye Level which was set up midway between the ends of the wire and about 12 feet from the wire. Rigid supports were provided at 25-foot intervals along the wire for securing the vernier sag gauge.

For each reading, the sag gauge was secured to the appropriate support. Referring to Figure 3, the limb of the gauge was then set in line with the horizontal stadia line of the telescope and a

reading taken on the vernier of the sag gauge. This position of the limb of the gauge indicated a point on a horizontal straight line passing through the support points. The limb of the gauge was then lowered to the wire and a reading taken on the vernier.


HEIGHT OF HORIZONTAL STRAIGHT LINE PASSING THRU WIRE AT SUPPORTING SHEAVES ESTABLISHED BY SIGHTS ON "WYE LEVEL."
SAG
WIRE
BASE CLAMPED TO RIGID SUPPORTS LOCATED AT 25 FT. INTERVALS ALONG LENGTH OF WIRE.

SAG GAGE USED FOR MEASURING SAG OF WIRE

FIG. 3

The difference between these two readings is the sag, or deflection, at that station between a true horizontal line and the actual position of the wire. The deflection was similarly measured at intervals of 25 feet along the wire. All readings were checked by individual observations of three men. White paper with a light directed upon it from behind was used as a background for the vernier slide, in order to clarify sights through the telescope of the Wye Level.

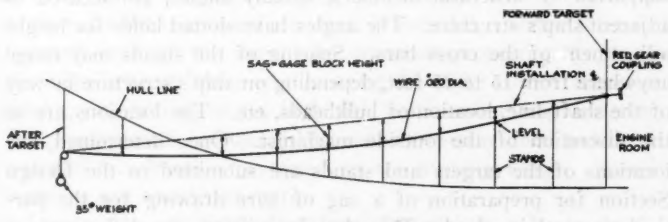
A comparison of the results obtained from the above procedure with computed deflections of a 300-foot span at 25-foot intervals, using the previously established $y^2 = 5440x$, was very favorable. For example, the deflection at the center of the span as measured was 4.052 inches and computed to be 4.136 inches, while, at 50 feet from the center, the figures were 3.606 inches and 3.592 inches respectively.

It is evident that, from the standpoint of practical application, the results of the foregoing justified continued use of the basic parabolic equation with the original constant ($2p = 5440$) for spans of any length up to 300 feet. In the last analysis, it is the correct installation and alignment of shafting that reduces the cost of maintenance and repair.

The sag method as described above has satisfactorily met every requirement for shaft installations.

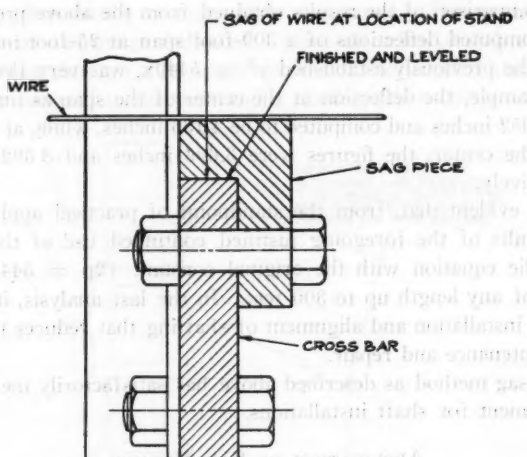
Application of Sag Method.

For running a shaft line on a vessel on the building ways, targets are established at the fore and aft ends of the line, normally at the forward bulkhead of the machinery space and at the centerline of the propeller, at the designed height and half breadth, if a twinscrew vessel. The wire is secured at the forward target and run over the same pulley with the same 35-pound weight attached at the after end as was used in the original experiment discussed above, so that the previously established curve will apply. (See Figure 4.)



ARRANGEMENT OF SAG STANDS ON SHIP FOR RUNNING WIRE.

FIG. 4



SAG STAND AND SAG PIECE

FIGURE 5.

Referring, now, to Figure 5, sag stands are set up directly under the wire. These stands, consisting of a machined cross bar supported by structural members, usually angles, are secured to adjacent ship's structure. The angles have slotted holes for height adjustment of the cross bars. Spacing of the stands may range anywhere from 15 to 25 feet, depending on ship's structure in way of the shaft line, location of bulkheads, etc. The locations are at the discretion of the outside machinist. Once determined, the locations of the targets and stands are submitted to the Design Section for preparation of a sag of wire drawing for the particular vessel involved. This drawing, giving the deflections of the wire at the stand locations, is then issued to the shops for prosecution of the work. Sag pieces (Figure 5) are made for each stand, finished machined to the drawing figures and are

equivalent to the amounts of deflection of the wire at the stand points.

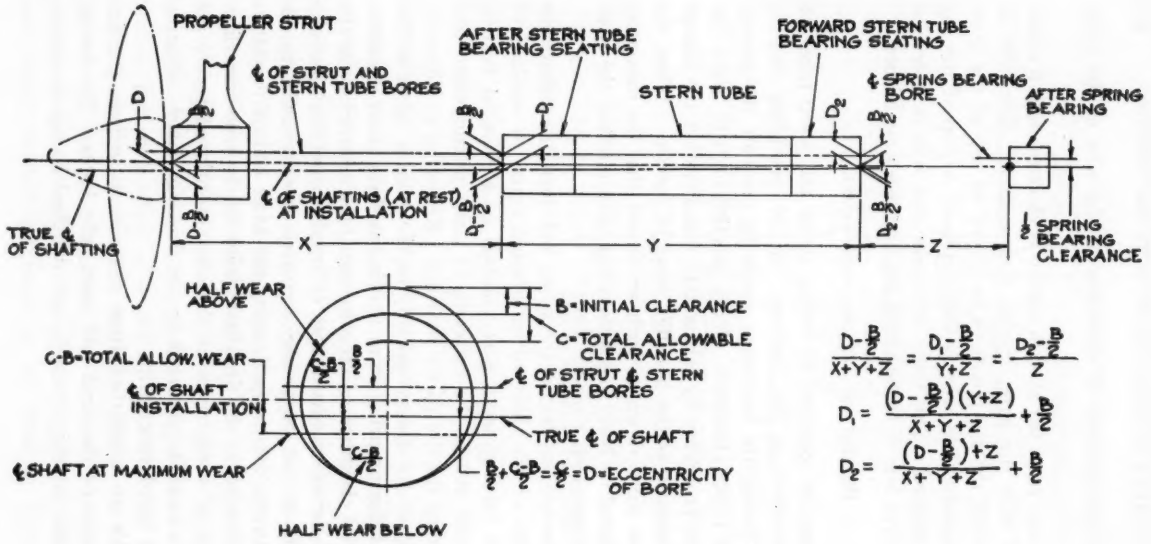
The sag stand cross bar at each station is elevated until it comes into contact with the wire, leveled and secured. The wire is moved to permit the sag pieces to be placed on top of the cross bars and secured. The wire is then replaced on top of the sag pieces and snapped a few times to assure that it is in a vertical plane. The true line of the shafting has now been established.

Boring of Struts and Tubes.

Former practice consisted of boring struts and stern tubes on the true centerline of the shafting, but of providing bearing clearance by boring the bushing eccentric by one-half the amount of minimum initial clearance. Navy practice in later years has improved this procedure by taking into consideration the change in shaft alignment as the bearings wear in service. When the bearings have worn down to such an extent that the maximum clearance allowed by Navy regulations has been reached, the bearings must be renewed.

It was reasoned that boring the struts and stern tubes above the true centerline of the shaft by an amount equal to one-half of the allowable bearing wear plus one-half of the initial bearing clearance would reduce the extremes of shaft misalignment and thereby lengthen the life of the bearings. Referring to Figure 6, the initial figure for the eccentricity of the bore is taken at the after face of the propeller strut and is based on shaft diameter, as is the initial clearance. Going forward, the eccentricity at the after end of the intermediate strut, if installed, and the after and forward ends of the stern tube decreases proportionally to the distances between these points, using the after end of the aftermost spring bearing as the first basic point on the true centerline. The amounts of eccentricity at the above-mentioned points are stamped in a location protected by the bushing flange. Bearing bushings are bored concentric.

Dart marks are established from the wire to indicate the finished diameters of the strut and stern tube bores. The boring bar is installed on the eccentric line and final boring is accomplished.



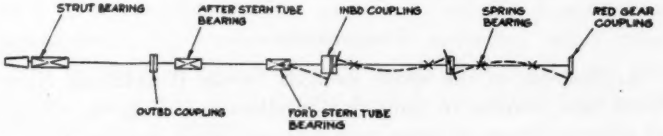
ECCENTRICITY OF BORES OF STRUTS AND STERN TUBES

FIG. 6

Prior to removal of the wire for boring, the heights of the main propulsion unit and spring bearing foundations are established. The spring bearing pedestals are bolted down with temporary bolts, liners being utilized to permit adjustment for final alignment. The vessel is now ready to receive the shafting.

Installation and Alignment of Shafting.

Upon completion of the machining of the shafting in the shop, with sleeves and stern tube shaft protective covering in place and prior to transmittal to the ship for installation, the individual shafts are set up for measurements of deflections, which are to be used in the final alignment of the shafting, as shown in Figure 7. Each shaft is set up on roller bearings whose center to



ELEVATION OF SHAFT

SHOP MEASUREMENT OF SHAFT DEFLECTIONS

FIG. 7

FIG. 6

center spacing and locations from shaft ends are in agreement with the designed shipboard installation. The propeller and stern tube shafts are coupled up for measurement of the deflection at the inboard coupling, since this is the starting point for alignment on the vessel. Measurements of deflections at each end of the line shafts, together with the inboard coupling, are recorded on a form (Figure 7) prepared by the Design Section and issued to the outside machinist for alignment purposes. Measurement of deflections of a single bearing shaft is accomplished by inserting a temporary roller at one end, usually at the end with the greatest overhang, to secure stability. On the vessel, the same roller is used in the same relative position as in the shop, to support the shaft prior to launching, aligning and coupling with the adjacent shaft.

The shafting is then shipped into the vessel and installed in the bearings. The propeller, intermediate, if installed, and stern tube shafts are permanently bolted up, the line shafts remaining uncoupled with flanges protected by boxing until the vessel is water borne, at which time final alignment is made.

With the vessel water borne and starting at the inboard coupling and moving forward, the shaft couplings are jacked up or down, as the case may be, by the amounts of deflections recorded as described above. Each coupling is brought into close proximity with the preceding one, which has been jacked on line, and the parallelism and concentricity of the coupling flange faces and peripheries checked. Spring bearing heights and athwartship locations are adjusted until the above readings are in close agreement, at which time final bolting up is accomplished.

Conclusions.

Applications of the above methods by the Philadelphia Navy Yard have resulted in many fine installations on a great number of different classes of ships, both large and small, and the Yard is proud of the excellent record established and maintained by the inside and outside machine shop personnel in sending out to sea first class installation of main propulsion shafting.

The writer wishes to acknowledge the assistance of Mr. R. F. Bushby, Chief Quarterman Machinist, Outside, in the preparation of this article.

SOME STEPS IN THE CONSERVATION OF CRITICAL MATERIALS—AN ATTEMPT TO SUBSTITUTE PHENOL FOR CRESOL IN CERTAIN LAMINATED PLASTICS.

By Mr. Jesse B. Lunsford.

The use of alternate materials is generally thought of in terms only of the present Wartime necessities—actually, however, the consideration of possible alternates is something which takes place normally, in all phases of electrical development; and particularly so in any paths leading towards the standardization of materials and equipment.

To illustrate one such analytical approach to a basic problem, let us take one case; one involving an attempted substitution of phenol for cresol in certain types of laminated plastics under Navy Specification 17P5 (INT). It is believed that this one example will show the scope of the industry problems involved in almost every case where, due to the ravages of the War's demands, it becomes necessary to seek an alternate material to serve in the place of one which has become critically short.

Most of our practices in the conservation of critical materials in this, the present war, were initiated before we became embroiled in the war; while others were initiated as long as ten years ago. This particular study included both these categories, and hence is particularly apt.

Cresol itself, originally only a by-product, amounts to a substitution program on its own account, beginning many years ago; but when cresol itself, in its new roll as a primary need, began to get scarce, then it became necessary to find a substitute for this substitute. This latter phase, in this particular case, occurred some weeks before our entrance into the present War.

In October, 1941, the Bureau received information to the effect that if the consumption of cresol was not drastically lowered, there might not be sufficient of it for all electrical applications. Specifically, the consumption of cresol, in the form of tricresyl phosphate, for use in electric cable (where the synthetics were substituted for rubber), was at such a high and increasing rate, that either more cresol would have to be produced, or else it would have to be rationed. The cresol needed for cable might have to come out of that needed so badly for plastics. The question then became one of "how", "where" and "when".

Unfortunately, the rapid increase in the usage of cresol for war purposes was accompanied by a dimunition in its rate of supply, because of the speed-up in the Steel Industry, i.e., the steps necessary to increase the coke production for increased steel production, would, of themselves, necessitate operation of the coking ovens at such temperatures and rates as would cut down on the unit quantities of cresol available as the "by-product". In short, "stepping-up" steel production automatically tended to "step-down" some other commodities, and this is particularly true of certain by-products, all other things being equal; in this particular case cresol in the particular fractions most desired, was the sufferer.

So, in October, 1941, we began to look about us to see if we could cut out cresol in certain plastics applications. Following this idea, a letter was addressed to all manufacturers of laminated phenolic materials, under Specification 17P5(INT)., inviting them to submit samples of new laminates for type or brand approval tests, in such formulations as might avoid the use, or at least diminish the use, of cresol. This letter was dated November 8, 1941, and it is believed that a reproduction of it here, in full, will be of interest in this connection.

November 8, 1941.

GENTLEMEN:

According to recent information received in the Bureau, it may be difficult in the near future to obtain sufficient cresol for the production of laminated phenolic material under Specification 17P5(INT) of 1 May, 1940. It is understood, however, that new

phenol resin varnishes are now available, which might be substituted for the creosol resin base varnishes now in wide use in the production of laminated phenolic materials.

It is the purpose of this letter, addressed to the various laminators of this class of material whose products have been tested and approved by the Bureau, to acquaint them with the reported, impending shortage of creosol base varnishes, in order that steps may be taken to obviate possible difficulties on this score. With this in mind, the Bureau proposes to institute a series of type or brand approval tests to provide an adequate source of alternate materials for use during the present emergency.

As your company has already had its product tested and approved under Specification 17P5, using creosol base varnishes, you are invited to submit for complete type or brand approval purposes such of your phenol resin base laminates as you may desire to offer for this purpose.

Specifically, the Bureau invites you to submit for such tests, samples covering Navy types FBG, FBM, FBE and PBM materials. These tests will be made without cost to you, other than the submission of the necessary test samples, all transportation charges prepaid. Furthermore, the tests will be expedited as much as practicable, and copies of the test reports furnished you in the usual manner upon completion of the tests.

If you desire to avail yourself of this opportunity to submit alternate materials for approval, you are urged to expedite the submission of the necessary samples in order that the minimum possible loss of time may ensue. It will greatly facilitate the testing of similar products of the several different manufacturers if these can be tested concurrently. You are, therefore, urged to submit the test specimens to the Material Laboratory, Building 22, Navy Yard, New York, N. Y., all transportation charges prepaid, in time for them to reach there at dates not later than the following:

Type	*Date*
FBG	1 December 1941
FBM	15 December 1941
FBE	29 December 1941
PBM	5 January 1942

Kindly indicate your intentions in this respect at the earliest practicable date."

Following this general invitation, all of the laminators submitted samples of the formulations which, in their own judgment, might best accomplish this purpose. Each of the laminators went about it in his own way; naturally the end results are rather widely variable. It is to be emphasized, however, that the laminators were freed from any restrictions by the Bureau in the accomplishment of the prime objective. It is the purpose of this article to cover this one case of proposed substitution and to illustrate, not only how far off some prognostications can sometimes be, even when it comes to some fields which have been reduced to an almost exact science; but even more, to point the way to some possible solutions in future endeavors along this particular line. If foresight has failed, maybe some hindsight might be helpful. It is believed that the presentation of some actual data, both in tabular and in graph form, will serve that purpose. There are also thrown in, for good measure, some conclusions arrived at here in the Bureau; these may, however, be disregarded without material loss.

Specifically, these laminates were furnished by each of the several manufacturers, in each of the following Navy types under Specification 17P5: FBG, FBM, FBE, PBM. Eleven laminators submitted a complete set of test specimens for each of the four types of materials. The picture which follows is based on the several arrangements of these data.

In presenting the general picture, let us take each of the four types of laminates tested (FBG, FBM, FBE and PBM) and make our comparisons of each in exactly the same order, viz.:

(*a*) Summary or recap sheet. (Table)
(*b*) General data breakdown. (Table)
(*c*) Comparison on basis of averages. (Discussion)
(*d*) Comparison of specific products. (Discussion)
(*e*) Product comparisons in graph form. (Chart)

TABLE I

TYPE PBM-NON-CONFORMITIES-SUMMARY OR RECAP SHEET

TABLE I

TYPE PBM-NON-CONFORMITIES-SUMMARY OR RECAP SHEET

Product	Fingerprints		Electrical Properties					Mechanical Properties														
	Water Absorption	Acetone Extraction	Insulation Resistance	Dielectric Strength				Impact Strength				Flexural Strength				Compressive Strength		Tensile Strength				Bonding Strength
				Parallel		Transverse		Lengthwise		Crosswise		Lengthwise		Crosswise				Lengthwise		Crosswise		
				s/t	s/by/s	s/t	s/by/s	Face	Side	Face	Side	Face	Side	Face	Side	Face	Side	1/8"	1/2"	1/8"	1/2"	
A	2.42		D			D																D
C	2.45		D																	D		

NOTE: The letter "D" as applied to the nonconformities shown in the Table above, refer to certain "Conditioning" regimes specified in 17P5(INT).

Type PBM
Cresol versus Phenol
Comparison of Average Values.

In the following discussion there is shown a detailed comparison, test by test, of the average mechanical and electrical properties of the phenol and the cresol resin laminates under Type PBM:

(*a*) While the percentage of water absorption and acetone extraction are not covered by the specification and are not, per se, measures of quality of the product, they are indicative of specific formulations and may therefore be utilized as "fingerprints" or "product identity" symbols. The average values are as follows:

	Phenol	*Cresol*
Water Absorption	2.13%*	1.34%
Acetone Extraction	4.65%	2.42%

(*b*) The average insulation resistance under condition D of the phenol product was found to be below specification requirements, and very much lower than that of the cresol product.

	Phenol	*Cresol*
For Condition B	200 + megohms	200 + megohms
For Condition D	.897*	28.01

(*c*) The average dielectric strength of the phenol product was found to be inferior to that of cresol resin material, but, in general, it is considerably above the specification requirements.

	Phenol			*Cresol*		
For Conditions	A	B	D	A	B	D
Parallel						
s/t	733	758	154	932	811	301.9
s/by/s	361	513	75	707	.....	177.8
Transverse						
s/t	.....	60	7.43	.....	108.1	8.02
s/by/s	.....	52.2	4.1	.....	76.2	13.5

(*d*) The average impact strength of the lengthwise samples of phenol products was found to be quite similar to that of cresol

		Product F	Product G	Product I		Average	
Water Absorption (1/8"; 24 hrs.; 25° C.)	Phenol	2.42*	1.59	2.45*		3.13*	Phenol
	Cresol	1.10	.81	2.1		1.34	Cresol
Acetone Extraction (1/8")	Phenol	7.39	1.66	4.90		4.65	Phenol
	Cresol	4.25	1.70	1.31		2.42	Cresol
Insulation Resistance							
Cond. B.	Phenol	3.8×10^4	3.2×10^4	1.1×10^4		2.7×10^4	Phenol
	Cresol	200+	200+	200+		200+	Cresol
Cond. D.	Phenol	0.87*	1.73	0.38*		.897*	Phenol
	Cresol	45	18.66	2.38		28.01	Cresol
Dielectric Strength							
Parallel S/T							
Cond. A.	Phenol	754	728	716		733	Phenol
	Cresol	932	---	---		932	Cresol
Cond. B.	Phenol	791	758	724		758	Phenol
	Cresol	931	761	741		811	Cresol
Cond. D.	Phenol	127	232	104		154	Phenol
	Cresol	593	215.6	97		301.9	Cresol
Parallel S/by/S							
Cond. A.	Phenol	460	442	480		361	Phenol
	Cresol	707	---	---		707	Cresol
Cond. B.	Phenol	615	470	454		513	Phenol
	Cresol	---	---	---		---	Cresol
Cond. D.	Phenol	64	98	64		75	Phenol
	Cresol	439	117.5	43		117.8	Cresol
Transverse S/T							
Cond. B.	Phenol	62	59.0	59	Volts/Mil	60	Phenol
	Cresol		123.7	92.5	"	108.1	Cresol
Cond. D.	Phenol	4.75*	11.9	6.25	"	7.43	Phenol
	Cresol		17.2	6.85	"	8.02	Cresol
Transverse S/by/S							
Cond. B.	Phenol	55	50.0	51.7	"	52.2	Phenol
	Cresol		73	79.4	"	76.2	Cresol
Cond. D.	Phenol	3.5	5.2	3.5	"	4.1	Phenol
	Cresol	22.7	11.7	6.2	"	13.5	Cresol
Impact Strength							
Lengthwise Face							
Cond. B.	Phenol	2.64	3.29	4.29	Ft.Lbs./In.Wd.	3.41	Phenol
	Cresol	2.80	2.60	4.59	"	3.33	Cresol
Cond. D.	Phenol	4.00	4.16	5.36	"	4.51	Phenol
	Cresol	6.07	3.00	3.52	"	4.16	Cresol
Cond. E.	Phenol	3.17	4.39	5.76	"	4.44	Phenol
	Cresol	5.28	3.41	5.46	"	4.72	Cresol
Lengthwise Side							
Cond. B.	Phenol	0.76	0.72	0.82	"	.77	Phenol
	Cresol	.72	.85	.73	"	.77	Cresol
Cond. D.	Phenol	1.09	0.85	1.24	"	1.06	Phenol
	Cresol	.87	.95	1.30	"	1.04	Cresol
Cond. E.	Phenol	0.80	0.97	1.10	"	.96	Phenol
	Cresol	1.23	.94	1.47	"	1.05	Cresol
Crosswise Face.							
Cond. B.	Phenol	2.13	2.43	2.67	"	1.41	Phenol
	Cresol	2.80	2.60	4.59	"	3.33	Cresol
Cond. D.	Phenol	3.17	2.47	3.48	"	3.04	Phenol
	Cresol	6.07	3.00	3.52	"	4.2	Cresol
Cond. E.	Phenol	2.71	2.82	3.30	"	2.94	Phenol
	Cresol	5.28	3.41	5.46	"	4.72	Cresol
Crosswise Side							
Cond. B.	Phenol	0.74	0.67	0.69	"	.70	Phenol
	Cresol	.72	0.85	.73	"	.77	Cresol
Cond. D.	Phenol	1.17	0.80	1.14	"	1.04	Phenol
	Cresol	.87	0.95	1.30	"	1.04	Cresol
Cond. E.	Phenol	0.82	0.90	0.91	"	.88	Phenol
	Cresol	1.23	0.94	1.47	"	1.21	Cresol
Flexural Strength							
Lengthwise Face							
Cond. A.	Phenol	24,800	31,230	28,200	p.s.i.	28,077	Phenol

Cond. B.	Phenol	0.74	0.67	0.69	"	.70	Phenol
	Cresol	.72	0.85	.73	"	.77	Cresol
Cond. D.	Phenol	1.17	0.80	1.14	"	1.04	Phenol
	Cresol	.87	0.95	1.30	"	1.04	Cresol
Cond. E.	Phenol	0.82	0.90	0.91	"	.86	Phenol
	Cresol	1.23	0.94	1.47	"	1.21	Cresol
Flexural Strength Lengthwise Face							
Cond. A.	Phenol	24,800	31,230	28,200	p.s.i.	28,077	Phenol
	Cresol	29,800	---	---	"	29,800	Cresol
Cond. B.	Phenol	27,200	30,440	30,900	"	29,513	Phenol
	Cresol	34,900	36,550	19,450	"	30,300	Cresol
Cond. D.	Phenol	12,900	18,280	15,900	"	15,693	Phenol
	Cresol	14,750	33,667	13,467	"	20,628	Cresol
Cond. E.	Phenol	13,100	31,030	22,200	"	22,110	Phenol
	Cresol	21,100	28,460	17,667	"	22,409	Cresol
Lengthwise Side							
Cond. A.	Phenol	24,800	31,590	28,000	"	28,130	Phenol
	Cresol	35,900		---	"	35,900	Cresol
Cond. B.	Phenol	27,200	31,320	31,000	"	29,840	Phenol
	Cresol	32,700	35,250	22,650	"	30,200	Cresol
Cond. D.	Phenol	12,900	30,670	28,400	"	23,990	Phenol
	Cresol	30,800	33,300	22,400	"	28,833	Cresol
Cond. E.	Phenol	13,100	30,710	25,100	"	22,970	Phenol
	Cresol	30,400	27,050	23,700	"	27,050	Cresol
Crosswise Face							
Cond. A.	Phenol	28,900	27,450	22,500	"	26,283	Phenol
	Cresol	29,800	---	---	"	29,800	Cresol
Cond. B.	Phenol	31,000	25,780	24,200	"	26,993	Phenol
	Cresol	34,900	36,550	19,450	"	30,300	Cresol
Flexural Strength Crosswise Face							
Cond. D.	Phenol	12,600	18,290	14,200	p.s.i.	15,030	Phenol
	Cresol	14,750	33,667	13,467	"	20,628	Cresol
Cond. E.	Phenol	13,300	24,590	18,600	"	18,830	Phenol
	Cresol	21,100	28,460	17,667	"	22,409	Cresol
Crosswise Side							
Cond. A.	Phenol	27,700	26,630	23,700	"	26,010	Phenol
	Cresol	35,900	---	---	"	35,900	Cresol
Cond. B.	Phenol	30,600	25,810	25,500	"	27,303	Phenol
	Cresol	32,700	35,250	22,650	"	30,200	Cresol
Cond. D.	Phenol	25,400	24,270	19,900	"	23,190	Phenol
	Cresol	30,800	33,300	22,400	"	28,833	Cresol
Cond. E.	Phenol	19,900	25,730	20,700	"	22,110	Phenol
	Cresol	30,400	27,050	23,700	"	27,050	Cresol
Compressive Strength Face							
Cond. A.	Phenol	48,000	50,620	47,500	"	48,707	Phenol
	Cresol	47,600	45,933	46,367	"	46,633	Cresol
Cond. B.	Phenol	45,700	54,110	46,900	"	48,903	Phenol
	Cresol	49,200	45,467	45,400	"	46,689	Cresol
Cond. D.	Phenol	28,300	37,460	28,100	"	31,287	Phenol
	Cresol	30,200	36,900	24,000	"	30,378	Cresol
Cond. E.	Phenol	28,000	43,570	33,300	"	34,957	Phenol
	Cresol	33,300	35,717	18,033	"	29,050	Cresol
Side							
Cond. A.	Phenol	22,000	25,910	25,200	"	24,370	Phenol
	Cresol	29,900	25,500	20,700	"	25,378	Cresol
Cond. B.	Phenol	23,100	27,820	24,700	"	25,208	Phenol
	Cresol	28,600	25,250	19,050	"	24,300	Cresol
Cond. D.	Phenol	13,000	16,720	10,700	"	13,473	Phenol
	Cresol	13,800	20,150	9,600	"	14,518	Cresol
Cond. E.	Phenol	10,900	23,420	15,600	"	16,640	Phenol
	Cresol	14,200	21,375	18,025	"	17,878	Cresol
Tensile Strength Lengthwise 1/8"							
Cond. A.	Phenol	17,300	18,830	25,500	"	20,543	Phenol
	Cresol	18,520	16,040	---	"	11,520	Cresol
Cond. B	Phenol	15,500	24,240	27,200	"	22,313	Phenol

Cond. E.	Phenol	2.71	2.85	3.30	"		
	Cresol	5.28	3.41	5.46	"	4.72	Cresol
Crosswise Side							
Cond. B.	Phenol	0.74	0.67	0.69	"	.70	Phenol
	Cresol	.72	0.85	.73	"	.77	Cresol
Cond. D.	Phenol	1.17	0.80	1.14	"	1.04	Phenol
	Cresol	.87	0.95	1.30	"	1.04	Cresol
Cond. E.	Phenol	0.82	0.90	0.91	"	.88	Phenol
	Cresol	1.23	0.94	1.47	"	1.21	Cresol
Flexural Strength Lengthwise Face							
Cond. A.	Phenol	24,800	31,230	28,200	p.s.i.	28,077	Phenol
	Cresol	29,800	---	---		29,800	Cresol
Cond. B.	Phenol	27,200	30,440	30,900	"	29,513	Phenol
	Cresol	34,900	36,550	19,450	"	30,300	Cresol
Cond. D.	Phenol	12,900	18,280	15,900	"	15,693	Phenol
	Cresol	14,750	33,667	13,467	"	20,628	Cresol
Cond. E.	Phenol	13,100	31,030	22,200	"	22,110	Phenol
	Cresol	21,100	28,460	17,667	"	22,409	Cresol
Lengthwise Side							
Cond. A.	Phenol	24,800	31,590	28,000	"	28,130	Phenol
	Cresol	35,900		---	"	35,900	Cresol
Cond. B.	Phenol	27,200	31,320	31,000	"	29,840	Phenol
	Cresol	32,700	35,250	22,650	"	30,200	Cresol
Cond. D.	Phenol	12,900	30,670	28,400	"	23,990	Phenol
	Cresol	30,800	33,300	22,400	"	28,833	Cresol
Cond. E.	Phenol	13,100	30,710	25,100	"	22,970	Phenol
	Cresol	30,400	27,050	23,700	"	27,050	Cresol
Crosswise Face							
Cond. A.	Phenol	28,900	27,450	22,500	"	26,283	Phenol
	Cresol	29,800	---	---	"	29,800	Cresol
Cond. B.	Phenol	31,000	25,780	24,200	"	26,993	Phenol
	Cresol	34,900	36,550	19,450	"	30,300	Cresol
Flexural Strength Crosswise Face							
Cond. D.	Phenol	12,600	18,290	14,200	p.s.i.	15,030	Phenol
	Cresol	14,750	33,667	13,467	"	20,628	Cresol
Cond. E.	Phenol	13,300	24,590	18,600	"	18,830	Phenol
	Cresol	21,100	28,460	17,667	"	22,409	Cresol
Crosswise Side							
Cond. A.	Phenol	27,700	26,630	23,700	"	26,010	Phenol
	Cresol	35,900	---	---	"	35,900	Cresol
Cond. B.	Phenol	30,600	25,810	25,500	"	27,303	Phenol
	Cresol	32,700	35,250	22,650	"	30,200	Cresol
Cond. D.	Phenol	25,400	24,270	19,900	"	23,190	Phenol
	Cresol	30,800	33,300	22,400	"	28,833	Cresol
Cond. E.	Phenol	19,900	25,730	20,700	"	22,110	Phenol
	Cresol	30,400	27,050	23,700	"	27,050	Cresol
Compressive Strength Face							
Cond. A.	Phenol	48,000	50,620	47,500	"	48,707	Phenol
	Cresol	47,600	45,933	46,367	"	46,633	Cresol
Cond. B.	Phenol	45,700	54,110	46,900	"	48,903	Phenol
	Cresol	49,200	45,467	45,400	"	46,689	Cresol
Cond. D.	Phenol	28,300	37,460	28,100	"	31,287	Phenol
	Cresol	30,200	36,900	24,000	"	30,378	Cresol
Cond. E.	Phenol	28,000	43,570	33,300	"	34,957	Phenol
	Cresol	33,300	35,717	18,033	"	29,050	Cresol
Side							
Cond. A.	Phenol	22,000	25,910	25,200	"	24,370	Phenol
	Cresol	29,900	25,500	20,700	"	25,378	Cresol
Cond. B.	Phenol	23,100	27,830	24,700	"	25,208	Phenol
	Cresol	28,600	25,250	19,050	"	24,300	Cresol
Cond. D.	Phenol	13,000	16,720	10,700	"	13,473	Phenol
	Cresol	13,800	20,150	9,600	"	14,518	Cresol
Cond. E.	Phenol	10,900	23,420	15,600	"	16,640	Phenol
	Cresol	14,200	21,375	18,025	"	17,878	Cresol
Tensile Strength Lengthwise 1/8"							
Cond. A.	Phenol	17,300	18,830	25,500	"	20,543	Phenol
	Cresol	18,520	16,040	---	"	11,520	Cresol
Cond. B.	Phenol	15,500	24,240	27,200	"	22,313	Phenol
	Cresol	18,440	18,200	---	"	12,213	Cresol
Cond. D.	Phenol	17,900	19,710	20,500	"	19,370	Phenol
	Cresol	22,500	16,070	---	"	12,857	Cresol

Cond. E.	Phenol	18,900	20,130	18,025	"	17,878	Cresol
	Cresol	14,200	21,375	18,025	"		
Tensile Strength Lengthwise 1/8"							
Cond. A.	Phenol	17,300	18,830	25,500	"	20,543	Phenol
	Cresol	18,520	16,040	---	"	11,520	Cresol
Cond. B.	Phenol	15,500	24,240	27,200	"	22,313	Phenol
	Cresol	18,440	18,200	---	"	12,213	Cresol
Cond. D.	Phenol	17,900	19,710	20,500	"	19,370	Phenol
	Cresol	22,500	16,070	---	"	12,857	Cresol
Cond. E.	Phenol	20,000	18,730	21,800	"	20,178	Phenol
	Cresol	19,960	15,300	---	"	11,753	Cresol
Lengthwise 1/2"							
Cond. A.	Phenol	16,800	21,110	27,300	"	21,738	Phenol
	Cresol	24,900	---	11,016	"	17,958	Cresol
Cond. B.	Phenol	17,900	26,070	25,000	"	22,990	Phenol
	Cresol	25,720	---	12,810	"	19,843	Cresol
Cond. D.	Phenol	21,300	21,370	24,000	"	22,223	Phenol
	Cresol	21,700	---	10,962*	"	16,331	Cresol
Cond. E.	Phenol	21,600	19,620	23,100	"	21,440	Phenol
	Cresol	16,780	---	9,140	"	12,960	Cresol
Crosswise 1/8"							
Cond. A.	Phenol	21,700	20,330	15,500	"	19,178	Phenol
	Cresol	18,520	19,270	---	"	18,895	Cresol
Cond. B.	Phenol	21,700	19,500	16,100	"	19,100	Phenol
	Cresol	18,440	19,590	---	"	19,015	Cresol
Cond. D.	Phenol	12,600	16,060	10,500*	"	13,053	Phenol
	Cresol	22,500	17,390	---	"	19,945	Cresol
Cond. E.	Phenol	14,200	15,230	12,900	"	14,110	Phenol
	Cresol	19,960	17,920	---	"	18,940	Cresol
Crosswise 1/2"							
Cond. A.	Phenol	18,800	21,330	15,900	Lbs./Sq.In	18,610	Phenol
	Cresol	24,900	---	11,016	"	17,958	Cresol
Cond. B.	Phenol	18,300	21,010	16,700	"	18,670	Phenol
	Cresol	25,720	---	12,800	"	19,260	Cresol
Cond. D.	Phenol	20,100	19,130	14,700	"	17,978	Phenol
	Cresol	21,700	---	10,962*	"	16,331	Cresol
Cond. E.	Phenol	21,300	18,550	13,800	"	14,550	Phenol
	Cresol	16,780	---	9,140	"	13,010	Cresol
Bonding Strength Lengthwise							
Cond. D.	Phenol	765	793	908	Lbs.	822	Phenol
	Cresol	815	---	---	"	815	Cresol
Cond. E.	Phenol	750	905	915	"	858	Phenol
	Cresol	916	---	---	"	916	Cresol
Crosswise							
Cond. D.	Phenol	563*	793	888	"	748	Phenol
	Cresol	845	---	---	"	815	Cresol
Cond. E.	Phenol	675	905	760	"	780	Phenol
	Cresol	916	---	---	"	916	Cresol

Note: Wherever an asterisk (*) is shown on the table, this indicates failure to comply with Navy specification requirements.

products. That of the crosswise samples, however, is somewhat lower than that of the cresol product. Both materials meet the specification requirements in all cases:

For Conditions	*Phenol* B	D	E	*Cresol* B	D	E
Lengthwise						
Face	3.41	4.51	4.44	3.33	4.16	4.72
Side	.77	1.06	.96	.77	1.04	1.05
Crosswise						
Face	1.41	3.04	2.94	3.33	4.2	4.72
Side	.70	1.04	.88	.77	1.04	1.21

(*e*) The average flexural strengths of both phenol and cresol products were found to be far above the specification requirements. The strength of the cresol product is, however, considerably higher than that of the phenol material.

For Conditions	*Phenol* A	B	D	E	*Cresol* A	B	D	E
Lengthwise								
Face	28,077	29,513	15,693	22,110	29,800	30,300	20,628	22,409
Side	28,130	29,840	23,990	22,970	35,900	30,200	28,833	27,050
Crosswise								
Face	26,283	26,993	15,030	18,830	29,800	30,300	20,628	22,409
Side	26,010	27,303	23,190	22,110	35,900	30,200	28,833	27,050

(*f*) In several cases the average compressive strength of the phenol product was found to be higher than that of the cresol product:

For Conditions	*Phenol* A	B	D	E	*Cresol* A	B	D	E
Face	48,707	48,903	31,287	34,957	46,633	46,689	30,378	29,050
Side	24,370	25,208	13,476	16,640	25,378	24,300	14,518	17,878

(*g*) The average tensile strength of the lengthwise samples of the phenol product was found to be much higher than that of the cresol product. The crosswise phenol samples compare fa-

vorably with those of the cresol product in this respect except under conditions D and E, ⅛-inch material, where the tensile strength was comparatively low:

For Conditions	*Phenol* A	B	D	E	*Cresol* A	B	D	E
Lengthwise								
⅛ inch	20,543	22,313	19,370	20,178	11,520	12,213	12,857	11,753
½ inch	21,738	22,990	22,223	21,440	17,958	19,843	16,331	12,960
Crosswise								
⅛ inch	19,178	19,100	13,053	14,110	18,895	19,015	19,945	18,940
½ inch	18,610	18,670	17,978	14,530	17,958	19,260	16,331	13,010

(*h*) The average bonding strength of the phenol product compares favorably with that of the cresol product:

For Conditions	*Phenol* D	E	*Cresol* D	E
Lengthwise	822	858	815	916
Crosswise	748	815	780	916

A Discussion Covering a Specific Example of Type PBM Laminate Identified as Product "I".

The following data, taken from the general data breakdown, Table I for Product "I", are discussed here for emphasis. If one so desired, he could take each of the other products and do exactly the same thing. It is believed, however, that Product "I" is fairly representative of the whole lot of Type PBM products. This example will, therefore, serve to emphasize what happens to one specific PBM laminate when an attempt is made to substitute phenol for cresol.

(*a*) While the water absorption and acetone extraction values are not of themselves any criterion of quality, and hence are not specified, they are indicative of a change in formulation and in that sense serve only as a "fingerprint" to "identify" the product:

	Phenol	*Cresol*
Water absorption	2.45*	2.10
Acetone extraction	4.90	1.31

(*b*) The insulation resistance under condition D is less than that required:

	Phenol	*Cresol*
For Condition B	200 +	200 +
For Condition D	0.38*	2.38

(*c*) The dielectric strength of both products was found to meet specification requirements. That of the cresol product was not, in several instances, a matter of record:

	Phenol			*Cresol*		
For Conditions	A	B	D	A	B	D
Parallel						
s/t	716	724	104	.....	741	97
s/by/s	480	454	64	.....	.....	43
Transverse						
s/t	.....	59	6.25	.....	92.5	6.85
s/by/s	.....	51.7	3.5	.....	79.4	6.2

(*d*) The impact strength of the crosswise samples of the cresol product was found to be better than that of the phenol product, but both products meet specification requirements:

	Phenol			*Cresol*		
For Conditions	B	D	E	B	D	E
Lengthwise						
Face	4.29	5.36	5.76	4.59	3.52	5.46
Side	.82	1.24	1.10	.73	1.30	1.47
Crosswise						
Face	2.67	3.48	3.30	4.59	3.52	5.46
Side	.69	1.14	.91	.73	1.30	1.47

(*e*) The flexural strengths of the phenol resin product were found to be considerably higher than those of the cresol product:

For Conditions	*Phenol* A	B	D	E	*Cresol* A	B	D	E
Lengthwise								
Face	28,200	30,900	15,900	22,200	.....	19,450	13,467	17,667
Side	28,000	31,000	28,400	25,100	.....	22,650	22,400	23,700
Crosswise								
Face	22,500	23,200	14,200	18,600	.....	19,450	13,467	17,667
Side	23,700	25,500	19,700	20,700	.....	22,650	22,400	23,700

(*f*) The compressive strength of the phenol resin product was found to be somewhat higher than that of the cresol product:

For Conditions	*Phenol* A	B	D	E	*Cresol* A	B	D	E
Face	47,500	46,900	28,100	33,300	46,367	45,500	24,000	18,033
Side	25,200	24,700	10,700	15,600	20,700	19,050	9,600	18,025

(*g*) The tensile strength of the phenol product was found to be very much superior to that of the cresol product:

For Conditions	*Phenol* A	B	D	E	*Cresol* A	B	D	E
Lengthwise								
⅛ inch	25,000	27,200	20,500	21,800	.....	.....	.....	.....
½ inch	27,300	25,000	24,000	23,100	11,016	12,810	10,962*	9,140
Crosswise								
⅛ inch	15,500	16,100	10,500*	12,900	.....	.....	.....	.....
½ inch	15,900	16,700	14,700	13,800	11,016	12,800	10,962*	9,140

(*h*) The bonding strength of the cresol product is not a matter of record, but the values for the phenol product were found to be:

For Condition	*Phenol* D	E	*Cresol*
Lengthwise	908	915	.....
Crosswise	888	760	.....

FIGURE 1

COMPARISON OF TYPE P B M PHENOL RESIN MATERIAL WITH P B M CRESOL RESIN MATERIAL

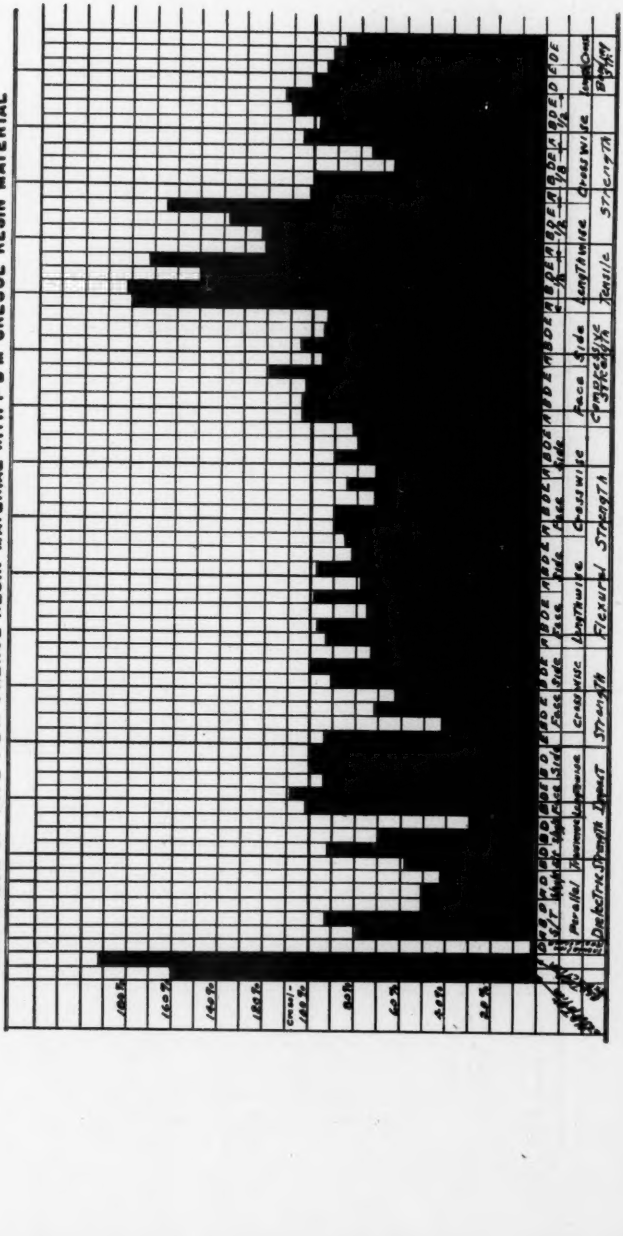


TABLE III

TYPE FBE-NON-CONFORMITIES-SUMMARY OR RECAP SHEET

Product	Fingerprints		Electrical Properties					Mechanical Properties														
				Dielectric Strength				Impact Strength				Flexural Strength				Compressive Strength		Tensile Strength				Bonding Strength
				Parallel		Transverse		Lengthwise		Crosswise		Lengthwise		Crosswise				Lengthwise		Crosswise		
	Water Absorption	Acetone Extraction	Insulation Resistance	s/t	s/by/s	s/t	s/by/s	Face	Side	Face	Side	Face	Side	Face	Side	Face	Side	1/8"	1/4"	1/8"	1/4"	
A									B,D													
B			E																			
C	1.23									B,D	B,D											
D											B											
E	1.26			A	A					B,D	B,D											
F					D			B,D	B	B	B,D			A, B,D	A, B,D	A				A	A	D,E
G	1.05				D																	
H					A									B								
I	.93				A																	
J	.99			B	A																	

NOTE: The letters A–B–D–E as applied to the nonconformities shown in the Table above, refer to certain "Conditioning" regimes specified in 17P5(INT).

NOTE: The letters A–B–D–E as applied to the nonconformities shown in the Table above, refer to certain "Conditioning" regimes specified in 17P5(INT).

GENERAL DATA BREAKDOWN NAVY TYPE FBE - TABLE IV

		Product A	Product B	Product C	Product E	Product G	Product F	Product H	Product J	Product K	Product I		Average	
Water Absorption	Phenol	.87	.68	1.23*	.86	1.26*	.63	1.05*	.71	.93*	.99*	%	.92	Phenol
	Cresol	.688	.537	.839	.590	.68	.58	.98	.60		.71	%	.7	Cresol
Acetone Extraction	Phenol	12.38	11.00	.58	4.78	1.36	8.88	1.21	6.14	3.47	6.12	%	5.59	Phenol
	Cresol	1.58	5.00	2.07	2.98	2.28	2.45	4.01	2.17		3.81	%	2.9	Cresol
Volume Resistance														
Cond. B.	Phenol	76,700	$17x10^4$	24,700	$2.3x10^4$	$10x10^3$	10^6	$2.7x10^4$	750,000	350,000	$9.6x10^4$	Megohms	---	Phenol
	Cresol	200+	200+	200+	200+	200+	200+	100+	200+		$100x10^3$	Megohms	---	Cresol
Cond. D.	Phenol	2,420	$5.4x10^2$	23,000	527	780	24.2	99	703	80,000	$3x10^4$	Megohms	---	Phenol
	Cresol	200+	200+	200+	79	37	10	100+	200+		16,333	Megohms	---	Cresol
Insulation Resistance														
Cond. D.	Phenol	42.0	4.8	2,930	5.75	56	4.5	3.7	4.7	200+	47	Megohms	329.8+	Phenol
	Cresol	7.1	8.1	200+	3.6	46.8	59	3.3	53.2		102	Megohms	53.6+	Cresol
Cond. E.	Phenol	20.3	1.2*	170	2.0	18	2.0	2.8	2.0	30	13	Megohms	26.1	Phenol
	Cresol	117	1.4*	81.2	46.7	24.2	81	25	79.6		41.7	Megohms	55.3	Cresol
Dielectric Strength														
Cond. A.	Phenol	461	373	393	416	308*	491	394	325*	392	381	Volts/Mil	393.4	Phenol
Parallel S/T	Cresol	368*	---	---	448	---	386	---	---		332*	Volts/Mil	384	Cresol
Cond. B.	Phenol	520	423	410	431	437	463	449	392	392	384*	Volts/Mil	430	Phenol
	Cresol	435	477	398	467	524	394	419	395		376*	Volts/Mil	432	Cresol
Cond. D.	Phenol	252	189	406	183	245	171	146	138	431	273	Volts/Mil	243.4	Phenol
	Cresol	200	280	385	186	183	171	102	132	[illegible]	319	Volts/Mil	224	Cresol
Parallel S/by/S														
Cond. A.	Phenol	316	310	275	305	227*	318	279	253*	260*	252*	Volts/Mil	274	Phenol
	Cresol	278		---	528	---	314	---			251*	Volts/Mil	343	Cresol
Cond. B.	Phenol	328	299	260	291	296	331	317	292	271	290	Volts/Mil	298	Phenol
	Cresol	325	360	322	355	349	311	402	298		272	Volts/Mil	333	Cresol
Cond. D.	Phenol	198	107	260	80	136	66*	67*	72	307	246	Volts/Mil	153.9	Phenol
	Cresol	133	130	304	128	82	125	65	103		319	Volts/Mil	157	Cresol
Cond. E.	Phenol	62.5	52	69.5	52	49	61	57	59.5	71	62	Volts/Mil	58.6	Phenol
Transverse	Cresol	---	132	---	45.3	---	84.7	84.9	77.1		97.3	Volts/Mil	86.4	Cresol
Cond. D.	Phenol	21.0	6.5	33.5	7.5	17	7.0	6.5	7.5	33	20	Volts/Mil	16	Phenol
	Cresol	44.3	31	30.3	9.4	---	9.6	5.9	7.7		57.9	Volts/Mil	24.5	Cresol
Cond. E.	Phenol	11.0	4.5	20.5	4.15	12.5	4.38	4.5	5.25	20.5	15	Volts/Mil	10.23	Phenol
	Cresol	38.9	12.9	23.6	5.9	---	7.3	4.9	9.1		35.1	Volts/Mil	17.2	Cresol
S/by/S														
Cond. B.	Phenol	51.7	57	60	51.7	45	53.3	51.7	73.3	68.3	53	Volts/Mil	56.5	Phenol
Transverse	Cresol	76.3	62.1	69.4	26.2	42.6	73.6	67.5	80		73.9	Volts/Mil	63.5	Cresol
Cond. D.	Phenol	16.7	6.7	24.2	5.83	8	6.0	5.5	7.5	25	15	Volts/Mil	12	Phenol
	Cresol	6.8	12.3	27.7	4.7	6.9	8.2	4.4	8.03		34.5	Volts/Mil	12.61	Cresol
Cond. E.	Phenol	17.2	3.3	29.7	3.33	7	5.67	3.8	9.0	15.3	12	Volts/Mil	10.6	Phenol
	Cresol	7.2	7.8	2.2*	5.5	4.5	6.3	4.7	5.7		22.2	Volts/Mil	7.3	Cresol
Impact Strength - Lengthwise Face														
Cond. B.	Phenol	2.27	3.07	2.62	2.70	2.71	1.77*	2.19	2.42	3.37	4.52	Ft.lbs/in Wd.	2.76	Phenol
	Cresol	1.82*	2.27	---	2.25	3.49	2.97	4.33	3.28		2.27	"	2.84	Cresol
Cond. D.	Phenol	2.18	3.22	3.05	2.96	2.77	1.86*	2.31	2.72	3.11	4.72	"	2.9	Phenol
	Cresol	1.94*	3.31	3.32	3.28	4.56	4.07	5.52	3.44		2.37	"	3.53	Cresol
Lengthwise Side														
Cond. B.	Phenol	1.12*	1.77	1.47	1.60	1.55	1.12*	1.51	1.66	1.93	2.13	"	1.59	Phenol
	Cresol	1.07*	1.37	---	1.58	1.26	2.02	3.36	2.24		1.39	"	1.79	Cresol
Cond. D.	Phenol	1.07*	1.75	1.60	1.63	1.66	1.24	1.59	1.76	1.78	2.21	"	1.63	Phenol

	Cresol	1.82*	2.27	---	2.25	3.49	2.97	4.33	3.28		2.27	"	2.84	Cresol
Cond. D.	Phenol	2.18	3.22	3.05	2.96	2.77	1.86*	2.31	2.72	3.11	4.72	"	2.9	Phenol
	Cresol	1.94*	3.31	3.32	3.28	4.56	4.07	5.52	3.44		2.37	"	3.53	Cresol
Lengthwise Side														
Cond. B.	Phenol	1.12*	1.77	1.47	1.60	1.55	1.12*	1.51	1.66	1.93	2.13	"	1.59	Phenol
	Cresol	1.07*	1.37	---	1.58	1.26	2.02	3.36	2.24		1.39	"	1.79	Cresol
Cond. D.	Phenol	1.07*	1.75	1.60	1.63	1.66	1.24	1.59	1.76	1.78	2.21	"	1.63	Phenol
	Cresol	1.10*	1.64	1.92	1.56	2.45	2.50	4.05	2.28		1.52	"	2.11	Cresol
Crosswise Face														
Cond. B.	Phenol	3.76	2.75	1.74*	2.29	1.67*	2.07*	2.80	2.17	2.57	4.46	"	2.63	Phenol
	Cresol	1.82*	2.27	---	2.25	3.49	2.97	4.33	3.28		2.24	"	2.83	Cresol
Cond. D.	Phenol	3.66	2.84	1.83*	2.33	1.75*	3.12	3.12	2.32	2.42	4.97	"	2.84	Phenol
	Cresol	1.94*	3.31	2.15	3.28	4.56	4.07	5.52	3.44		2.42	"	3.41	Cresol
Crosswise Side														
Cond. B.	Phenol	1.91	1.38	.97*	1.23*	.93*	1.10*	1.52	1.26	1.29	2.18	"	1.36	Phenol
	Cresol	1.07*	1.37	---	1.58	1.26	2.02	3.36	2.24		1.40	"	1.79	Cresol
Cond. D.	Phenol	1.88	1.40	1.08*	1.27	1.00*	1.14*	1.52	1.35	1.26	2.24	"	1.41	Phenol
	Cresol	1.10*	1.64	1.30	1.56	2.45	2.50	4.05	2.28		1.54	"	2.05	Cresol
Flexural Strength- Lengthwise Face														
Cond. A.	Phenol	16,120	22,400	27,360	22,720	21,270	17,740	19,900	19,590	28,210	27,040	Lbs/sq.in.	22,235	Phenol
	Cresol	11,680*	18,380	23,930	15,300	---	19,670	23,500	23,370		18,900	"	19,341	Cresol
Cond. B.	Phenol	16,730	22,870	31,710	23,730	22,970	16,830*	20,300	19,320	29,750	28,430	"	23,264	Phenol
	Cresol	10,440*	21,260	---	16,000	17,333	19,000	24,700	23,830		20,430	"	19,249	Cresol
Cond. D.	Phenol	20,520	23,000	30,090	23,190	22,500	15,350	19,900	19,490	30,550	30,500	"	23,509	Phenol
	Cresol	11,400*	19,660	26,500	14,700	19,966	21,470	28,100	24,330		21,430	"	20,840	Cresol
Lengthwise Side														
Cond. A.	Phenol	16,100	20,700	27,090	21,010	20,280	16,380	19,100	17,430	28,120	26,500	"	21,270	Phenol
	Cresol	10,200*	15,750	26,130	13,700	---	16,070	20,250	22,770		21,460	"	18,241	Cresol
Cond. B.	Phenol	18,080	21,800	30,560	21,180	22,630	15,400	20,200	20,380	29,130	28,230	"	22,759	Phenol
	Cresol	11,000*	20,380	---	14,600	17,085	18,230	24,500	22,830		22,400	"	18,878	Cresol
Cond. D.	Phenol	20,220	23,300	30,920	22,230	22,970	15,760	21,400	21,290	31,280	31,200	"	24,057	Phenol
	Cresol	12,800*	21,100	28,200	14,800	19,325	19,270	27,100	24,800		23,230	"	21,181	Cresol
Crosswise Face														
Cond. A.	Phenol	21,320	18,070	20,260	17,950	16,170	12,080*	16,800	15,140	17,090	27,600	"	18,248	Phenol
	Cresol	11,680*	18,380	17,130	15,300	---	19,670	23,500	23,370		20,160	"	18,649	Cresol
Cond. B.	Phenol	22,150	18,500	22,070	18,190	15,550	11,240*	17,300	13,840	16,120	27,000	"	18,196	Phenol
	Cresol	10,440	21,260	---	16,000	17,333	19,000	24,700	23,830		21,130	"	19,224	Cresol
Cond. D.	Phenol	25,780	18,700	22,220	18,810	15,630	11,010*	17,700	16,940	19,140	25,870	"	19,180	Phenol
	Cresol	11,400*	19,660	18,860	14,700	19,966	21,470	28,100	24,330		21,860	"	20,038	Cresol
Crosswise Side														
Cond. A.	Phenol	21,150	18,400	20,520	17,010	14,630	12,300*	16,900	14,300	18,520	25,200	"	17,893	Phenol
	Cresol	10,200*	15,750	18,360	13,700		16,070	20,250	22,770		21,430	"	17,316	Cresol
Cond. B.	Phenol	23,940	18,600	22,340	17,140	16,620	11,680*	18,500	15,580	16,740	26,130	"	18,727	Phenol
	Cresol	11,000*	20,380	---	14,600	17,085	18,230	24,500	22,830		19,600	"	18,528	Cresol
Cond. D.	Phenol	26,760	19,200	24,130	18,680	17,600	13,080*	19,500	16,600	19,220	30,600	"	20,537	Phenol
	Cresol	12,800*	21,100	21,660	14,800	19,325	19,270	27,100	24,800		23,000	"	20,428	Cresol
Compressive Strength Face														
Cond. A.	Phenol	36,500	40,600	47,960	42,290	41,200	33,140*	41,700	38,550	45,540	45,500	"	41,298	Phenol
	Cresol	40,200	44,670	43,800	38,200	41,217	41,030	36,800	42,730		27,700	"	40,150	Cresol
Side	Phenol	22,980	26,600	29,840	18,880	29,100	29,060	26,400	28,370	29,210	26,870	"	27,731	Phenol
	Cresol	31,000	29,000	28,800	27,000	29,925	29,700	28,500	28,430		25,800	"	28,462	Cresol

	Cresol	200	280	365	186	183	171	102	132	[illegible]	314	Volts/Mil	224	Cresol
Parallel S/by/S														
Cond. A.	Phenol	316	310	275	305	227*	318	279	253*	260*	252*	Volts/Mil	274	Phenol
	Cresol	278		---	528	---	314	---			251*	Volts/Mil	343	Cresol
Cond. B.	Phenol	328	299	260	291	290	331	317	292	271	290	Volts/Mil	298	Phenol
	Cresol	325	360	322	355	349	311	402	298		272	Volts/Mil	333	Cresol
Cond. D.	Phenol	198	107	260	80	136	66*	67*	72	307	246	Volts/Mil	153.9	Phenol
	Cresol	133	130	304	128	82	125	85	103		319	Volts/Mil	157	Cresol
Cond. E.	Phenol	62.5	52	69.5	52	49	61	57	59.5	71	52	Volts/Mil	58.6	Phenol
Transverse	Cresol	---	132	---	45.3	---	84.7	84.9	77.1		97.3	Volts/Mil	86.4	Cresol
Cond. D.	Phenol	21.0	6.5	33.5	7.5	17	7.0	6.5	7.5	33	20	Volts/Mil	16	Phenol
	Cresol	44.3	31	30.3	9.4	---	9.6	5.9	7.7		57.9	Volts/Mil	24.5	Cresol
Cond. E.	Phenol	11.0	4.5	20.5	4,15	12.5	4.38	4.5	5.25	20.5	15	Volts/Mil	10.23	Phenol
	Cresol	38.9	12.9	23.6	5.9	---	7.3	4.9	9.1		35.1	Volts/Mil	17.2	Cresol
S/by/S														
Cond. B.	Phenol	51.7	57	60	51.7	45	53.3	51.7	73.3	68.3	53	Volts/Mil	56.5	Phenol
Transverse	Cresol	76.3	62.1	69.4	26.2	42.6	73.6	67.5	80		73.9	Volts/Mil	63.5	Cresol
Cond. D.	Phenol	16.7	6.7	24.2	5.83	8	6.0	5.5	7.5	25	15	Volts/Mil	12	Phenol
	Cresol	6.8	12.3	27.7	4.7	6.9	8.2	4.4	8.03		34.5	Volts/Mil	12.61	Cresol
Cond. E.	Phenol	17.2	3.3	29.7	3.33	7	5.67	3.8	9.0	15.3	12	Volts/Mil	10.6	Phenol
	Cresol	7.2	7.8	2.2*	5.5	4.5	6.3	4.7	5.7		22.2	Volts/Mil	7.3	Cresol
Impact Strength - Lengthwise Face														
Cond. B.	Phenol	2.27	3.07	2.62	2.70	2.71	1.77*	2.19	2.42	3.37	4.52	Ft.lbs/in Wd.	2.76	Phenol
	Cresol	1.82*	2.27	---	2.25	3.49	2.97	4.33	3.28		2.27	"	2.84	Cresol
Cond. D.	Phenol	2.18	3.22	3.05	2.96	2.77	1.86*	2.31	2.72	3.11	4.72	"	2.9	Phenol
	Cresol	1.94*	3.31	3.32	3.28	4.56	4.07	5.52	3.44		2.37	"	3.53	Cresol
Lengthwise Side														
Cond. B.	Phenol	1.12*	1.77	1.47	1.60	1.55	1.12*	1.51	1.66	1.93	2.13	"	1.59	Phenol
	Cresol	1.07*	1.37	---	1.58	1.26	2.02	3.36	2.24		1.39	"	1.79	Cresol
Cond. D.	Phenol	1.07*	1.75	1.60	1.63	1.66	1.24	1.59	1.76	1.78	2.21	"	1.63	Phenol
	Cresol	1.10*	1.64	1.92	1.56	2.45	2.50	4.05	2.28		1.52	"	2.11	Cresol
Crosswise Face														
Cond. B.	Phenol	3.78	2.75	1.74*	2.29	1.67*	2.07*	2.80	2.17	2.57	4.46	"	2.63	Phenol
	Cresol	1.82*	2.27	---	2.25	3.49	2.97	4.33	3.28		2.24	"	2.83	Cresol
Cond. D.	Phenol	3.66	2.84	1.83*	2.33	1.75*	3.12	3.12	2.32	2.42	4.97	"	2.84	Phenol
	Cresol	1.94*	3.31	2.15	3.28	4.56	4.07	5.52	3.44		2.42	"	3.41	Cresol
Crosswise Side														
Cond. B.	Phenol	1.91	1.38	.97*	1.23*	.93*	1.10*	1.52	1.26	1.29	2.18	"	1.38	Phenol
	Cresol	1.07*	1.37	---	1.58	1.26	2.02	3.36	2.24		1.40	"	1.79	Cresol
Cond. D.	Phenol	1.88	1.40	1.08*	1.27	1.00*	1.14*	1.52	1.35	1.26	2.24	"	1.41	Phenol
	Cresol	1.10*	1.64	1.30	1.56	2.45	2.50	4.05	2.28		1.54	"	2.05	Cresol
Flexural Strength- Lengthwise Face														
Cond. A.	Phenol	16,120	22,400	27,360	22,720	21,270	17,740	19,900	19,590	28,210	27,040	Lbs/sq.in.	22,235	Phenol
	Cresol	11,680*	18,380	23,930	15,300	---	19,670	23,500	23,370		18,900	"	19,341	Cresol
Cond. B.	Phenol	16,730	22,870	31,710	23,730	22,970	16,830	20,300	19,320	29,750	28,430	"	23,264	Phenol
	Cresol	10,440*	21,260	---	16,000	17,333	19,000	24,700	23,830		20,430	"	19,249	Cresol
Cond. D.	Phenol	20,520	23,000	30,090	23,190	22,500	15,350	19,900	19,490	30,550	30,500	"	23,509	Phenol
	Cresol	11,400*	19,660	26,500	14,700	19,966	21,470	28,100	24,330		21,430	"	20,840	Cresol
Lengthwise Side														
Cond. A.	Phenol	16,100	20,700	27,090	21,010	20,280	16,380	19,100	17,430	28,120	26,500	"	21,270	Phenol
	Cresol	10,200*	15,750	26,130	13,700	---	16,070	20,250	22,770		21,460	"	18,241	Cresol
Cond. B.	Phenol	18,080	21,800	30,560	21,180	22,630	15,400	20,200	20,380	29,130	28,230	"	22,759	Phenol
	Cresol	11,000*	20,380	---	14,600	17,085	18,230	24,500	22,830		22,400	"	18,878	Cresol
Cond. D.	Phenol	20,220	23,300	30,920	22,230	22,970	15,760	21,400	21,290	31,280	31,200	"	24,057	Phenol
	Cresol	12,800*	21,100	28,200	14,800	19,325	19,270	27,100	24,800		23,230	"	21,181	Cresol

Lengthwise Side														
Cond. A.	Phenol	16,100	20,700	27,090	21,010	20,280	16,380	19,100	17,430	28,120	26,500	"	21,270	Phenol
	Cresol	10,200*	15,750	26,130	13,700	---	16,070	20,250	22,770		21,460	"	18,241	Cresol
Cond. B.	Phenol	18,080	21,800	30,560	21,180	22,630	15,400	20,200	20,380	29,130	28,230	"	22,759	Phenol
	Cresol	11,000*	20,380	---	14,600	17,085	18,230	24,500	22,830		22,400	"	18,878	Cresol
Cond. D.	Phenol	20,220	23,300	30,920	22,230	22,970	15,760	21,400	21,290	31,280	31,200	"	24,057	Phenol
	Cresol	12,800*	21,100	28,200	14,800	19,325	19,270	27,100	24,800		23,230	"	21,181	Cresol
Crosswise Face														
Cond. A.	Phenol	21,320	18,070	20,260	17,950	16,170	12,080*	16,800	15,140	17,090	27,600	"	18,248	Phenol
	Cresol	11,680*	18,380	17,130	15,300	---	19,870	23,500	23,370		20,160	"	18,649	Cresol
Cond. B.	Phenol	22,150	18,500	22,070	18,190	15,550	11,240*	17,300	13,840	16,120	27,000	"	18,196	Phenol
	Cresol	10,440	21,260	---	16,000	17,333	19,000	24,700	23,830		21,130	"	19,224	Cresol
Cond. D.	Phenol	25,780	18,700	22,220	18,810	15,630	11,010*	17,700	16,940	19,140	25,870	"	19,180	Phenol
	Cresol	11,400*	19,660	18,860	14,700	19,966	21,470	28,100	24,330		21,860	"	20,038	Cresol
Crosswise Side														
Cond. A.	Phenol	21,150	18,400	20,520	17,010	14,630	12,300*	16,900	14,300	18,520	25,200	"	17,893	Phenol
	Cresol	10,200*	15,750	18,360	13,700		16,070	20,250	22,770		21,430	"	17,316	Cresol
Cond. B.	Phenol	23,940	18,600	22,340	17,140	16,620	11,680*	18,500	15,580	16,740	26,130	"	18,727	Phenol
	Cresol	11,000*	20,380	---	14,600	17,085	18,230	24,500	22,830		19,600	"	18,528	Cresol
Cond. D.	Phenol	26,760	19,200	24,130	18,680	17,600	13,080*	19,500	16,600	19,220	30,600	"	20,537	Phenol
	Cresol	12,800*	21,100	21,660	14,800	19,325	19,270	27,100	24,800		23,000	"	20,428	Cresol
Compressive Strength														
Face														
Cond. A.	Phenol	36,500	40,600	47,960	42,290	41,200	33,140*	41,700	38,550	45,540	45,500	"	41,298	Phenol
	Cresol	40,200	44,670	43,800	38,200	41,217	41,030	36,800	42,730		27,700	"	40,150	Cresol
Side	Phenol	22,980	26,600	29,840	18,880	29,100	29,060	26,400	28,370	29,210	26,870	"	27,731	Phenol
	Cresol	31,000	29,000	26,800	27,000	29,925	29,700	28,500	28,430		25,800	"	28,462	Cresol
Tensile Strength														
Lengthwise 1/8"	Phenol	11,600	11,500	19,750	12,970	14,700	9,860	13,200	10,660	18,690	16,330	"	14,126	Phenol
Cond. A.	Cresol	8,600	12,630	16,500	6,960*	---	12,160	---	10,210		13,830	"	11,584	Cresol
1/2"	Phenol	11,940	9,380	20,450	13,050	10,130	9,700	13,500	11,610	19,380	16,230	"	13,737	Phenol
	Cresol	---	12,500	20,600	8,140	10,396	---	9,700	14,190		12,760	"	12,612	Cresol
Crosswise 1/8"	Phenol	16,050	8,770	15,150	8,540	8,750	6,230*	9,170	7,540	10,110	10,420	"	10,073	Phenol
	Cresol	8,600	10,235	10,900	6,960*	---	12,160	---	10,210		7,930	"	9,571	Cresol
1/2"	Phenol	15,990	12,700	14,790	9,680	9,270	6,800*	9,190	8,890	10,300	13,380	"	11,099	Phenol
	Cresol	---	10,700	13,900	8,140	10,396	---	9,700	14,190		8,066	"	10,727	Cresol
Bonding Strength														
Cond. D.	Phenol	1,569	1,610	2,148	1,770	1,983	1,398	1,845	1,770	1,928	1,510	Lbs	1,753	Phenol
	Cresol	1,954	---	1,880	---	---	2,262	1,858	1,983		1,776	"	1,952	Cresol
Cond. E.	Phenol	1,512	1,540	1,933	1,675	1,733	1,378*	1,730	1,920	1,788	1,590	"	1,680	Phenol
	Cresol	1,890	---	1,830	---	---	1,950	1,824	2,072	---	1,700	"	1,878	Cresol

Note: Wherever an asterisk (*) is shown on the table, this indicates failure to comply with Navy specification requirements.

TYPE FBE
CRESOL VERSUS PHENOL
COMPARISON OF AVERAGE VALUES.

In the following discussion there is shown a detailed comparison, test by test, of the average mechanical and electrical properties of the phenol and cresol resin laminates under Type FBE:

(*a*) While the percentage of water absorption and acetone extraction are not covered by the specification and are not, per se, measures of quality of the product, they are indicative of specific formulations and may, therefore, be utilized as "fingerprints" or "product identity" symbols. The average values are as follows:

	Phenol	*Cresol*
Water Absorption	.92	.7
Acetone Extraction	5.59	2.9

(*b*) The average insulation resistance under Condition D of the phenol product was found to be much higher than that of the cresol product, while under Condition E the insulation resistance of the cresol product is double that of the phenol product. Both materials met the specification requirements for these tests:

	Phenol	*Cresol*
For Condition D	329.8 megohms	53.6 megohms
For Condition E	26.1 megohms	55.3 megohms

(*c*) The average dielectric strength of the phenol product is in general lower than that of the cresol resin material particularly in the short time tests on the transverse samples.

	Phenol			*Cresol*		
For Conditions	A	B	D	A	B	D
Parallel						
s/t	393.4	430	243.4	384	432	224
s/by/s	274	298	153.9	343	333	157

For Conditions	B	D	E	B	D	E
Transverse						
s/t	58.6	16	10.23	86.4	24.5	17.2
s/by/s	56.5	12	10.6	63.5	12.61	7.3

(*d*) The average impact strength of the samples of the phenol products was found to be lower than that of the samples of the cresol products in every instance. The average impact strength of both materials met the specification requirements.

	Phenol		*Cresol*	
For Conditions	B	D	B	D
Lengthwise				
Face	2.76	2.9	2.84	3.53
Side	1.59	1.63	1.79	2.11
Crosswise				
Face	2.63	2.84	2.83	3.41
Side	1.38	1.41	1.79	2.05

(*e*) The average flexural strengths of the phenol products compare very favorably with those of the cresol products. In the case of the lengthwise samples, the average flexural strength of the phenol products was found to be considerably higher than that of the cresol products.

	Phenol			*Cresol*		
For Conditions	A	B	D	A	B	D
Lengthwise						
Face	22,235	23,264	23,509	19,341	19,249	20,840
Side	21,270	22,759	24,057	18,241	18,878	21,181
Crosswise						
Face	18,248	18,196	19,180	18,649	19,224	20,038
Side	17,893	18,727	20,537	17,316	18,528	20,428

(*f*) The phenol and cresol products of this type were found to have fairly similar average compressive strengths.

	Phenol	*Cresol*
Face	41,298	40,150
Side	27,731	28,462

(*g*) The phenol products in each case have a higher average tensile strength than that of the cresol products.

	Phenol	*Cresol*
Lengthwise ⅛ inch	14,126	11,584
½ inch	13,737	12,612
Crosswise ⅛ inch	10,073	9,571
½ inch	11,099	10,727

(*h*) The average bonding strengths of both the phenol and cresol products were well above the specification requirements. That of the cresol products was greater, however, than that of the phenol materials.

	Phenol	*Cresol*
Condition D	1753	1952
Condition E	1680	1878

DISCUSSION COVERING A SPECIFIC EXAMPLE OF TYPE FBE LAMINATE IDENTIFIED AS PRODUCT "F".

1. The following data, taken from the general data breakdown, Table II for Product "F", are discussed here for emphasis. If one so desired, he could take each of the other nine products and do exactly the same thing. It is believed, however, that Product "F" is fairly representative of the whole lot of Type FBE products. This example will, therefore, serve to emphasize what happens to one specific FBE laminate when an attempt is made to substitute phenol for cresol.

(*a*) While water absorption and acetone extraction values are not of themselves any criterion of quality, and hence are not specified, they are indicative of a change in formulation, and in that sense, serve only as a "fingerprint" to "identify" the product.

	Phenol	*Cresol*
Water Absorption	.63	.68
Acetone Extraction	8.88	2.45

(*b*) The volume resistance of the phenol product under Condition D is higher than that of cresol:

Phenol	*Cresol*
24.2	10

(*c*) The insulation resistance of the cresol product greatly exceeded that of the phenol product:

	Phenol	*Cresol*
For Condition D	4.5	59
For Condition E	2.0	81

(*d*) The dielectric strength of the sample in the parallel direction was found to be equal to or greater than that of the corresponding cresol sample, except under Condition D. The transverse samples of the phenol product were found to have a lower dielectric strength than those of the cresol product:

	Phenol			*Cresol*		
For Conditions	A	B	D	A	B	D
Parallel						
s/t	491	463	171	386	394	171
s/by/s	318	331	66*	314	311	125
Transverse						
s/t	61	7.0	4.38	84.7	9.6	7.3
s/by/s	53.3	6.0	5.67	73.6	8.2	6.3

(*e*) The impact strength of the phenol resin product was found to be not only lower than that of the cresol resin product, but in most cases it does not meet the specification requirements:

	Phenol		*Cresol*	
For Conditions	B	D	B	D
Lengthwise				
Face	1.77*	1.86*	2.97	4.07
Side	1.12*	1.24	2.02	2.50

Crosswise				
Face	2.07*	3.12	2.97	4.07
Side	1.10*	1.14*	2.02	2.50

(*f*) The flexural strength of the phenol resin product was found to be inferior to that of the cresol product. In the crosswise direction, the phenol samples were below specification requirements:

	Phenol			*Cresol*		
For Conditions	A	B	D	A	B	D
Lengthwise						
Face	17,740	16,830	15,350	19,670	19,000	21,470
Side	16,380	15,400	15,760	16,070	18,230	19,270
Crosswise						
Face	12,080*	11,240*	11,010*	19,670	19,000	21,470
Side	12,300*	11,680*	13,080*	16,070	18,230	19,270

(*g*) The compressive strength of the cresol product was found to be greater than that of the phenol material:

	Phenol	*Cresol*
Face	33,140*	41,030
Side	29,060	29,700

(*h*) The tensile strength of the phenol product was found to be less than that of the cresol product. The crosswise ⅛-inch and ½-inch samples did not meet specification requirements:

	Phenol	*Cresol*
Lengthwise ⅛ inch	9,860	12,160
½ inch	9,700	.....
Crosswise ⅛ inch	6,230*	12,160
½ inch	6,800*	.....

(*i*) The bonding strength of the phenol resin product was found to be below the specification requirements:

	Phenol		*Cresol*	
For Conditions	D	E	D	E
	1,398*	1,378	2,262	1,950

FIGURE 2
COMPARISON OF TYPE F B E PHENOL RESIN MATERIAL WITH F B E CRESOL RESIN MATERIAL

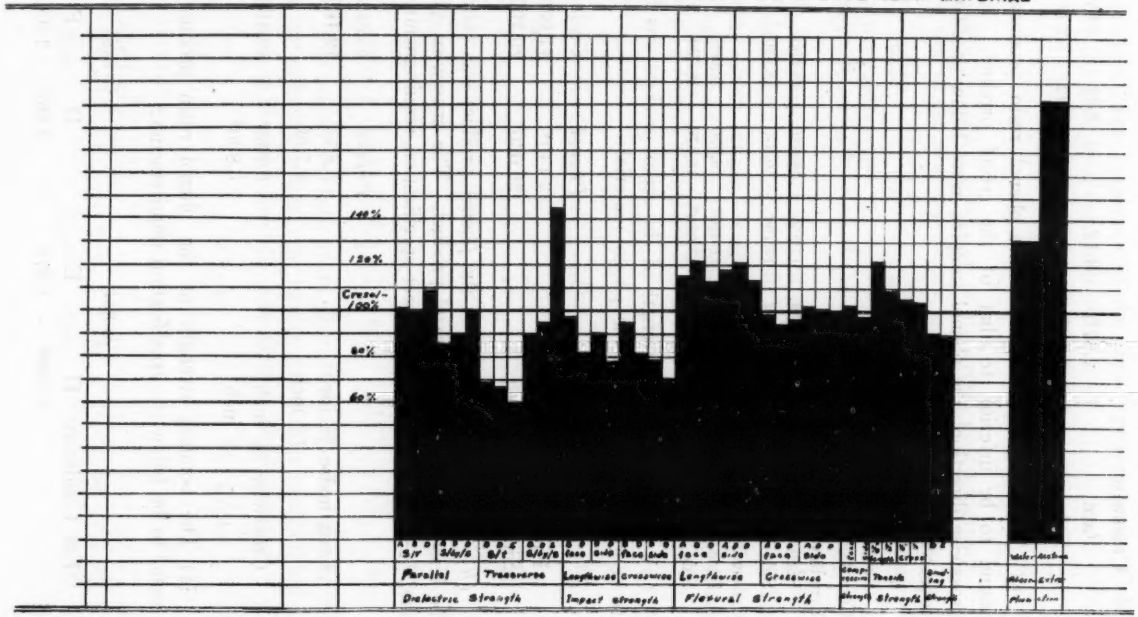


TABLE V

TABLE V

TYPE FBG-NON-CONFORMITIES-SUMMARY OR RECAP SHEET

Product	Fingerprints		Electrical Properties					Mechanical Properties														
	Water Absorption	Acetone Extraction	Insulation Resistance	Dielectric Strength				Impact Strength				Flexural Strength				Compressive Strength		Tensile Strength				Bonding Strength
				Parallel		Transverse		Lengthwise		Crosswise		Lengthwise		Crosswise				Lengthwise		Crosswise		
				s/t	s/by/s	s/t	s/by/s	Face	Side	Face	Side	Face	Side	Face	Side	Face	Side	1/8"	1/2"	1/8"	1/2"	
A										D		A,B	B	A		A	A				A	
B								D	B,D	B,D	B,D	A,B		A				A		A		
C								D	B,D	D	D	A		A								E
D										D	B,D	A		A, B,D	B,D					A	A	D,E
E								B,D	B,D	B,D	B,D	A,B	B,D	A, B,D	A, B,D			A	A	A	A	
F								D	B,D	B,D	B,D			A, B,D	A, B,D					A	A	D,E
G								D		D		A		A, B,D						A	A	
H			D,E			B	D			B,D	B,D			A, B,D	B,D					A		
I										D	B,D											D,E
J	2.56																					

NOTE: The letters A–B–D–E as applied to the nonconformities shown in the Table above, refer to certain "Conditioning" regimes specified in 17P5(INT).

Type FBG
Cresol versus Phenol
Comparison of Average Values.

In the following discussion there is shown a detailed comparison, test by test, of the average mechanical and electrical properties of the phenol and the cresol resin laminates under Type FBG:

(*a*) While the percentage of water absorption and acetone extraction are not covered by the specification and are not, per se, measures of quality of the product, they are indicative of specific formulations and may therefore be utilized as "fingerprints" or "product identity" symbols. The average values are as follows:

	Phenol	*Cresol*
Water Absorption	99%	.706%
Acetone Extraction	5.31%	3.04%

(*b*) The insulation resistance of the phenol products under Condition D is nearly three times that of the cresol products; while in Condition E, the insulation resistance of the cresol resin is more than three times that of the phenol products:

	Phenol	*Cresol*
Condition D	36.8 megohms	13.2 megohms
Condition E	8.07 megohms	29.67 megohms

(*c*) The dielectric strength of both phenol and cresol products meet the specification requirements, and their values are fairly similar except in the following respects:

Parallel to molding pressure, s/by/s, Condition D, where the dielectric strength of the phenol resin is slightly more than 30 per cent higher than that of the cresol resin.

Transverse to molding pressure, s/t, Condition B, where the dielectric strength of the cresol resin is considerably higher than that of the phenol resin.

	Phenol				*Cresol*			
For Conditions	A	B	D	E	A	B	D	E
Parallel								
s/t	321	401	179	.....	331	387	164	.....
s/by/s	248	284	112	.....	253	284	85.3	.....

rison,
erties
G:
e ex-
er se,
ecific
" or
lows:

nder
ucts;
resin

ducts
fairly

e the
0 per

e the
than

E

GENERAL DATA BREAKDOWN NAVY TYPE XEO - TABLE VI

		Product A	Product B	Product C	Product D	Product E	Product F	Product G	Product H	Product I		Average	
Water Absorption	Phenol	.84	.53	1.08	1.22	.42	.59	1.46*	1.70*	1.07	%	.90%	Phenol
	Cresol	.592	.47	1.1	.92	.349	.76	.497	.945	.72	%	.706%	Cresol
Acetone Extraction	Phenol	8.36	12.54	1.31	6.63	4.46	6.91	1.64	1.27	6.45	%	5.51%	Phenol
	Cresol	3.14	1.30	1.65	3.67	2.55	3.81	2.28	4.11	4.83	%	3.04%	Cresol
Insulation Resistance													
Cond. D.	Phenol	14.0	158	8	3.3	90	4.0	26	1.10*	27	Megohms	36.6	Phenol
	Cresol	30.1	7.8	10.9	1.8	4.8	4.7	53.6	1.02*	4.4	"	13.2	Cresol
Cond. E.	Phenol	3.73	3.43	6.3	7.0	11	7.8	16	1.47*	16	"	8.07	Phenol
	Cresol	88.7	23.7	.41*	17.3	8.6	24.2	74	3.26	28	"	29.67	Cresol
Dielectric Strength Paralled S/T													
Cond. A.	Phenol	337	328	315	---	302	290*	312	307	318	Volts/Mil.	321	Phenol
	Cresol	331	---	---	---	---	---	---	---	---	"	331	Cresol
Cond. B.	Phenol	378	352	405	522	315	400	375	493	369	"	401	Phenol
	Cresol	391	386	440	428	339	451	428	357	261	"	387	Cresol
Cond. D.	Phenol	88	200	197	103	310	222	201	69	224	"	179	Phenol
	Cresol	245	197	473	105	95	129	97.5	92	40.4	"	164	Cresol
Parallel S/by/S													
Cond. A.	Phenol	257	250	244	---	244	253	245	261	229	"	248	Phenol
	Cresol	253	---	---	---	---	---	---	---	---	"	253	Cresol
Cond. B.	Phenol	319	258	258	390	242	250	245	331	261	"	284	Phenol
	Cresol	301	255	361	343	207	338	344.6	236	168	"	284	Cresol
Cond. D.	Phenol	59	128	97	67	259	93.6	99	31	175	"	112	Phenol
	Cresol	150	88	202	62	47	77	65.2	50	26.3	"	85.3	Cresol
Transverse S/T													
Cond. B.	Phenol	47	85	68.5	50.5	62	62	61	42*	57	"	59.4	Phenol
	Cresol	74	111		57	92.4	114	83	89.2	52.7	"	84.2	Cresol
Cond. D.	Phenol	9.0	18	10.5	7.75	24	7.5	19	4.25	21	"	13.4	Phenol
	Cresol	13.3	14		4.8	9.5	19.9	12.3	7.9	10.3	"	11.5	Cresol
Cond. E.	Phenol	4.25	4.63	6.75	5.25	8.8	4.0	14	3.75	13.5	"	7.21	Phenol
	Cresol	6.9	8.7		4.15	8	14.4	5.4	4.2	6.6	"	7.26	Cresol
Transverse S/by/S													
Cond. B.	Phenol	65	70	67	52	63	55	60	46.7	62	""	60.1	Phenol
	Cresol	55.5	49	64.5	46	74	78.8	84.4	69.7	23.1	"	60.6	Cresol
				51,400* *									
Cond. D.	Phenol	6.8	9	5.5	5.33	15.2	7.7	8.8	3.0*	12.5	"	8.2	Phenol
	Cresol	6.7	6	7.3									
				5,920* *	3.8	6.4	6.1	8.3	4.4	5.4	"	6.04	Cresol
Cond. E.	Phenol	4.67	4.50	3.8	5.00	5.00	3.7	6	2.67	9,0	"	4.93	Phenol
	Cresol	5.7	4.05	12.2									
				9,880* *	3.9	6.3	6.1	4.74	4.1	4.2	"	5.7	Cresol
Impact Strength Lengthwise Face											Ft.lbs./in.		
Cond. B.	Phenol	4.00	3.34	3.18	6.12	2.79*	3.58	4.52	5.99	5.32	Width	4.32	Phenol
	Cresol	7.88	2.99*	7.76	5.89	5.7	4.91	6.21	5.59	4.61	"	5.73	Cresol
Cond. D.	Phenol	4.53	3.24*	3.57*	7	2.77*	3.49*	4.21*	5.95	5.39	"	4.46	Phenol
	Cresol	8.53	4.47	9.28	6.20	6.48	5.65	7.61	5.57	5.13	"	6.55	Cresol
Lengthwise Side													
Cond. B.	Phenol	2.62	1.93*	2.00*	2.97	2.02*	1.94*	3.55	2.96	2.58	"	2.51	Phenol
	Cresol	4.14	2.35	4.56	3.50	3.65	2.43	4.53	3.57	4.10	"	3.65	Cresol
Cond. D.	Phenol	2.45	2.06*	2.05*	3.33	1.84*	2.14*	2.57	3.36	2.74	"	2.5	Phenol
	Cresol	4.82	2.55	4.61	4.14	3.61	2.79	4.95	3.93	4.32	"	3.97	Cresol
Crosswise Face													
Cond. B.	Phenol	3.16	2.53*	3.23	3.69	2.90*	1.74*	3.60	2.23*	3.65	"	2.97*	Phenol
	Cresol	4.81	2.99*	7.76	5.89	5.7	4.91	6.21	5.59	4.61	"	5.39	Cresol
Cond. D.	Phenol	4.14*	2.63*	3.88*	3.87*	3.10*	1.67*	4.03*	2.32*	3.82*	"	3.27*	Phenol
	Cresol	4.99	4.47	9.28	6.20	6.48	5.65	7.61	5.57	5.13	"	6.15	Cresol
Crosswise Side													
Cond. B.	Phenol	2.40	1.57*	2.10	1.69*	2.06*	1.28*	2.18	1.47*	1.78*	"	1.84*	Phenol
	Cresol	2.84	2.35	4.56	3.50	3.65	2.43	4.53	3.57	4.10	"	3.5	Cresol
Cond. D.	Phenol	2.63	1.62*	2.08*	1.72*	1.93*	1.36*	2.45	1.57*	1.86*	"	1.91*	Phenol
	Cresol	3.27	2.55	4.61	4.14	3.61	2.79	4.95	3.93	4.32	"	3.8	Cresol
Flexural Strength Lengthwise Face													
Cond. A.	Phenol	16,830*	17,890*	17,130*	18,390*	15,920*	19,200	18,580*	25,350	24,600	p.s.i.	19,321	Phenol
	Cresol	19,000	19,166	---	19,500	---	24,400	---	19,600	---	"	20,333	Cresol

Crosswise Side													
Cond. B.	Phenol	2.40	1.57*	2.10	1.69*	2.06*	1.28*	2.18	1.47*	1.78*	"	1.84*	Phenol
	Cresol	2.84	2.35	4.56	3.50	3.65	2.43	4.53	3.57	4.10	"	3.5	Cresol
Cond. D.	Phenol	2.63	1.62*	2.08*	1.72*	1.93*	1.36*	2.45	1.57*	1.86*	"	1.91*	Phenol
	Cresol	3.27	2.55	4.61	4.14	3.61	2.79	4.95	3.93	4.32	"	3.8	Cresol
Flexural Strength													
Lengthwise Face													
Cond. A.	Phenol	16,830*	17,890*	17,130*	18,390*	15,920*	19,200	18,580*	25,350	24,600	p.s.i.	19,321	Phenol
	Cresol	19,000	19,166	---	19,500	---	24,400	---	19,600	---	"	20,333	Cresol
Cond. B.	Phenol	17,380*	17,520*	20,180	19,930	16,270*	20,200	18,980	25,400	26,900	"	20,307	Phenol
	Cresol	19,300	19,233	23,100	19,200	24,950	23,930	23,750	18,700	17,966*	"	21,125	Cresol
Cond. D.	Phenol	18,900	18,170	20,310	20,650	17,470	18,700	18,530	24,660	26,730	"	20,458	Phenol
	Cresol	18,700	18,866	19,300	20,100	27,800	23,266	23,850	17,000	17,650	"	20,726	Cresol
Lengthwise Side													
Cond. A.	Phenol	16,770	17,240	19,300	20,370	15,740	17,200	16,520	23,280	27,150	"	19,386	Phenol
	Cresol	18,800	17,650	---	19,100	---	21,950	---	15,350	---	"	18,570	Cresol
Cond. B.	Phenol	16,770*	18,020	19,880	20,620	17,360*	19,000	19,510	25,020	27,010	"	20,347	Phenol
	Cresol	19,200	18,550	18,700	19,200	23,500	21,500	26,750	17,600	19,100	"	20,456	Cresol
Cond. D.	Phenol	19,540	18,970	20,860	20,290	17,610*	18,000	19,290	23,690	28,050	"	20,700	Phenol
	Cresol	19,500	21,475	18,000	19,800	25,700	23,525	27,525	19,800	18,425	"	21,528	Cresol
Crosswise Face													
Cond. A.	Phenol	16,880*	17,740*	18,230*	15,840*	15,070*	13,000*	17,780*	16,830*	20,340	"	16,857*	Phenol
	Cresol	20,800	19,166	---	19,500	---	24,400	---	19,600	---	"	20,693	Cresol
Cond. B.	Phenol	18,080	18,130	19,520	16,980*	15,580*	13,700*	16,580*	16,530*	21,670	"	17,419	Phenol
	Cresol	21,500	19,233	23,100	19,200	26,000	23,930	23,750	18,700	17,966*	"	21,487	Cresol
Cond. D.	Phenol	19,080	17,950	20,070	16,950*	15,340*	14,400*	17,100	15,770*	21,760	"	17,802	Phenol
	Cresol	21,500	18,866	19,300	20,100	28,600	23,266	23,850	17,000	17,650	"	21,126	Cresol
Crosswise Side													
Cond. A.	Phenol	17,600	16,290	17,810	16,020	14,630*	12,200*	17,490	16,060	19,760	"	16,428	Phenol
	Cresol	20,400	17,650	---	19,100	---	21,950	---	15,350	---	"	18,890	Cresol
Cond. B.	Phenol	17,500	18,030	19,540	16,830*	14,470*	13,500*	19,470	16,350*	21,470	"	17,462*	Phenol
	Cresol	21,100	18,550	18,700	19,200	23,350	21,500	26,750	17,600	19,100	"	20,761	Cresol
Cond. D.	Phenol	19,850	18,200	21,160	17,110*	16,460*	12,600*	19,430	16,770*	22,710	"	18,254	Phenol
	Cresol	21,500	21,475	18,000	19,800	25,050	23,525	27,525	19,800	16,425	"	21,789	Cresol
Compressive Strength													
Face.													
Cond. A.	Phenol	36,290*	42,110	44,280	42,460	42,600	37,100	44,520	44,670	43,050	"	41,898	Phenol
	Cresol	40,833	43,133	40,800	39,300	44,800	43,233	47,933	36,900	41,500	"	42,048	Cresol
Side													
Cond. A.	Phenol	22,250*	27,650	27,560	28,080	28,560	28,200	26,500	28,480	22,470	"	26,639	Phenol
	Cresol	29,200	31,825	23,200	23,700	30,250	30,800	29,583	22,400	26,300	"	27,373	Cresol
Tensile Strength													
Lengthwise 1/8"													
Cond. A.	Phenol	9,060	7,510*	12,210	10,600	7,870*	9,000	12,850	13,870	18,050	p.s.i.	11,224	Phenol
	Cresol	8,080*	10,050	15,160	13,120	(Average) 11,340	8,988*	---	---	---	"	11,123	Cresol
Lengthwise 1/2"													
Cond. A.	Phenol	10,060	9,360	11,600	11,220	8,820*	10,220	10,000	14,650	18,680	"	11,623	Phenol
	Cresol	---	9,250	---	---	11,340	---	11,484	10,860	10,926	"	10,772	Cresol
Crosswise 1/8"													
Cond. A.	Phenol	9,540	8,690*	9,800	8,460*	7,600*	6,320*	7,440*	8,110*	10,250	"	8,461*	Phenol
	Cresol	9,140	8,090*	15,160	13,120	11,340	8,988*	---	---	---	"	10,937	Cresol
Crosswise 1/2"													
Cond. A.	Phenol	8,860*	9,860	10,900	8,910*	7,040*	6,320*	8,860*	9,260	12,580	"	9,234	Phenol
	Cresol	---	8,290*	---	---	11,340	---	11,484	10,860	10,926	"	10,580	Cresol
Bonding Strength													
Cond. D.	Phenol	1,860	1,770	1,632	1,008*	2,000	1,400*	2,047	1,817	1,430*	lbs.	1,663	Phenol
	Cresol	2,157	(Average) 2,253	---	2,125	---	---	---	1,625	---	"	1,969	Cresol
Cond. E.	Phenol	1,870	1,930	1,728*	943*	1,910	1,280*	1,872	1,991	1,320*	"	1,649*	Phenol
	Cresol	2,295	(Average) 2,253	---	2,134	---	---	---	1,850	---	"	2,093	Cresol

**Volts/gap (.812)

Note: Wherever an asterisk (*) is shown on the table, this indicates failure to comply with Navy specification requirements.

Transverse								
s/t	.....	.....	13.4	7.21	.....	.....	11.5	7.26
s/by/s	.....	60.1	8.20	4.93	.....	60.6	60.4	5.7

(*d*) In every case the average impact strength of cresol resin products was found to be greater than that for the phenol resin products. The average impact strength of the phenol resin products fell below the specified requirements where the sample was cut crosswise:

For	*Phenol*		*Cresol*	
Conditions	B	D	B	D
Lengthwise				
Face	4.32	4.46	5.73	6.55
Side	2.51	2.5	3.65	3.97
Crosswise				
Face	2.97*	3.27*	5.39	6.15
Side	1.84*	1.91*	3.5	3.8

(*e*) The average flexural strengths for crosswise samples of phenol resin products were found, in every case, to be considerably lower than the flexural strengths of the corresponding cresol resin products. In three instances the crosswise phenol samples failed to meet specification requirements. The flexural strengths of the lengthwise samples of the phenol resin products was only slightly lower than those for the corresponding samples of cresol products.

For	*Phenol*			*Cresol*		
Conditions	A	B	D	A	B	D
Lengthwise						
Face	19,321	20,307	20,458	20,333	21,125	20,726
Side	19,285	20,347	20,700	18,570	20,456	21,528
Crosswise						
Face	16,857*	17,419*	17,602	20,693	21,487	21,126
Side	16,428	17,462*	18,254	18,890	20,761	21,789

(*f*) The compressive strengths of the phenol products were found to be well above the specification requirements, but slightly lower than those of the cresol resin products:

	Phenol	*Cresol*
Face	41,898	42,048
Side	26,639	27,373

(*g*) Crosswise samples of phenol products have a lower average tensile strength than the corresponding samples of cresol products. The average tensile strengths of the ⅛-inch phenol samples are below specification requirements. The tensile strengths of the lengthwise phenol products are greater than those of the cresol samples, but values for both are higher than specification requirements:

	Phenol	*Cresol*
Lengthwise ⅛-inch	11,224	11,123
½-inch	11,623	10,772
Crosswise ⅛-inch	8,461*	10,937
½-inch	9,234	10,580

(*h*) In Condition E the bonding strengths of the phenol resin products were far below specification requirements. Those of the cresol resin products are considerably above present specification requirements:

	Phenol	*Cresol*
Condition D	1663	1969
Condition E	1649	2093

Discussion Covering a Specific Example of Type FBG Laminate Identified as Product "F".

The following data, taken from the general data breakdown, Table III for Product "F", are discussed here for emphasis. If one so desired, he could take each of the other eight products and do exactly the same thing. It is believed, however, that Product "F" is fairly representative of the whole lot of Type FBG products. This example will, therefore, serve to emphasize what happens to one specific FBG laminate when an attempt is made to substitute phenol for cresol.

(*a*) While water absorption and acetone extraction values are not of themselves any criterion of quality, and hence are not

* Does not meet specification requirements.

specified, they are indicative of a change in formulation and in that sense serve only as a "fingerprint" or "product identity":

	Phenol	*Cresol*
Water Absorption	.59	.76
Acetone Extraction	6.91	3.81

(*b*) The insulation resistance of the cresol product is much higher than that of the phenol resin.

	Phenol	*Cresol*
For Condition D	4.0	4.7
For Condition E	7.8	24.2

(*c*) In most cases, the dielectric strength of the cresol material is better than that of the phenol resin material. In only one case was the dielectric strength of the phenol product below the Navy specification requirements:

For	*Phenol*				*Cresol*			
Conditions	A	B	D	E	A	B	D	E
Parallel								
s/t	290*	400	232	.....	.....	451	129	.....
s/by/s	253	250	936	.....	.....	338	77	.....
Transverse								
s/t	.....	62	7.5	4.0	.....	114	19.9	14.4
s/by/s	.....	55	7.7	3.7	.....	78.8	6.1	6.1

(*d*) In every case but one, the impact strength of the phenol resin product was found to be below Navy specification requirements. In this respect, it is very inferior to the cresol resin products material.

For	*Phenol*		*Cresol*	
Conditions	B	D	B	D
Lengthwise				
Face	3.58	3.49*	4.91	5.65
Side	1.94*	2.14*	2.43	2.79
Crosswise				
Face	1.74*	1.67*	4.91	5.65
Side	1.28*	1.36*	2.43	2.79

(*e*) The flexural strengths of the cresol products are far greater than those of the phenol products. The flexural strengths of the crosswise samples for phenol resin products were found to be below Navy specification requirements:

For Conditions	*Phenol* A	B	D	*Cresol* A	B	D
Lengthwise						
Face	19,200	20,200	18,700	24,400	23,950	23,266
Side	17,200	19,000	18,000	21,950	21,500	23,525
Crosswise						
Face	13,000*	13,700*	14,400*	24,400	23,930	23,266
Side	12,200*	13,500*	12,600*	21,950	21,500	23,525

(*f*) The compressive strengths of the phenol resin products were found to be below those of the cresol resin products:

	Phenol	*Cresol*
Face	37,100	43,233
Side	28,200	30,800

(*g*) The tensile strengths, for both phenol and cresol products, for this particular laminator, were low:

	Phenol	*Cresol*
Lengthwise ⅛-inch	9,000	8,988*
½-inch	10,220	.....
Crosswise ⅛-inch	6,320*	8,988*
½-inch	6,820*	.....

(*h*) No bonding strength data were obtained on the cresol resin products. Those of the phenol resin products are, however, below Navy Specification requirements:

	Phenol	*Cresol*
Condition D	1,400*	.....
Condition E	1,280*	.....

* Does not meet specification requirements.

FIGURE 3

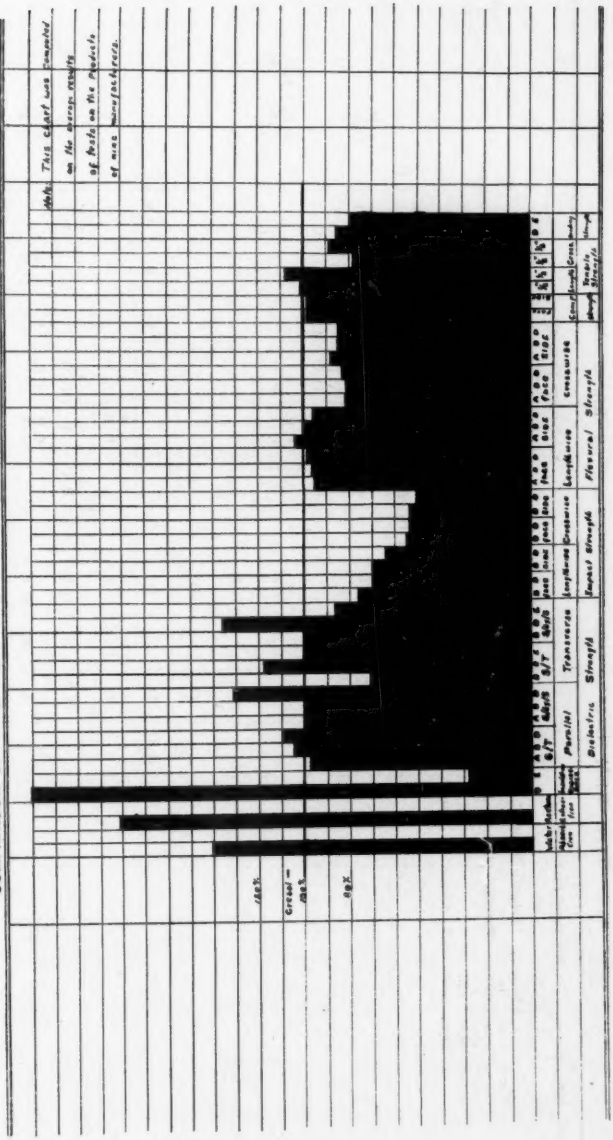


FIGURE 3

COMPARISON OF TYPE F B G PHENOL MATERIAL WITH CRESOL RESIN MATERIAL

TABLE VII

TYPE FBM-NON-CONFORMITIES-SUMMARY OR RECAP SHEET

Product	Fingerprints		Electrical Properties					Mechanical Properties														
	Water Absorption	Acetone Extraction	Insulation Resistance	Dielectric Strength				Impact Strength				Flexural Strength				Compressive Strength		Tensile Strength				Bonding Strength
				Parallel		Transverse		Lengthwise		Crosswise		Lengthwise		Crosswise				Lengthwise		Crosswise		
				s/t	s/by/s	s/t	s/by/s	Face	Side	Face	Side	Face	Side	Face	Side	Face	Side	¼"	½"	⅛"	½"	
A								D				A B,D	A B,D	A,B	A B,D	A,B D,E		A,B D,E	A D	A,D		
B								B D,E	B D,E	B D,E	D,E		A,B					A, D,E		A,B, D,E		
C										D,E		D	A B,D	A,D	A, B, D,E	A,D						
D										B D,E	B D,E			A,B, D,E	A, B,D					A,B, D,E	A,B, D,E	
E									D,E		D,E				A							D
F			D				D		D		D	B	A		A							
G			D				D	B,D	D		D				A,B	D	B	D,E				
H									D	B D,E	B D,E			A,B, D,E	A, B,D					A, D,E		
I								D	D,E	D	D,E	A	A B,D	A	A B,D			A,B, D,E		D		
J	2.56			A			B		E	E	D,E			A,B, D,E	A,B, D,E	A, D,E	A,B, D,E			A,B, D,E		

NOTE: The letters A–B–D–E as applied to the nonconformities shown in the Table above, refer to certain "Conditioning" regimes specified in 17P5(INT).

NOTE: The letters A–B–D–E as applied to the nonconformities shown in the Table above, refer to certain "Conditioning" regimes specified in 17P5(INT).

GENERAL DATA BREAKDOWN NAVY TYPE FSM - TABLE VIII

		Product A	Product B	Product C	Product D	Product E	Product G	Product F	Product H	Product J	Product I		Average	
Water Absorption	Phenol	.78	.93	1.88	.87	.91	1.41	2.10	2.14	.94	2.56*		1.25	Phenol
	Cresol	.701	.78	1.2	.354	.349	2.35	2.81*	1.12	.63	1.14		1.14	Cresol
Acetone Extraction	Phenol	7.11	6.43	1.18	6.48	5.50	1.53	7.19	3.18	4.76	5.65		4.90	Phenol
	Cresol	2.21	5.0	3.05	3.37	2.55	2.15	2.32	2.80	2.29	4.42		3.02	Cresol
Insulation Resistance														
Cond. B.	Phenol	22,000	16,300	9,170	11,900	13,900	3,270	3,200	4,300	26,700	350		11,049	Phenol
	Cresol	200+	200+	200+	200+	100+	200+	200+	200+	100+	200+		---	Cresol
Cond. D.	Phenol	2.92	.93	.92	6.7	1.50	.53*	.57*	.83	4.53	.6		1.4	Phenol
	Cresol	3.58	1.54	9.0	2.14	4.82	.79	.52*	1.84	23	3.17		5.04	Cresol
Dielectric Strength Parallel S/T														
Cond. A.	Phenol	353	331	287	400	315	307	387	359	306	149*		319	Phenol
	Cresol	359	---	---	---	---	---	---	---	---	---		359	Cresol
Cond. D.	Phenol	112	86.8	47.9	198	96	85.8	24.4	86.2	159	52.5		94.9	Phenol
	Cresol	172	57.1	134	105	95	4.6	12	136	75.3	31.6		86.6	Cresol
Parallel S/by/S														
Cond. A.	Phenol	239	241	218	278	255	216	270	246	248	---		246	Phenol
	Cresol	289	---	---	---	---	---	---	---	---	---		289	Cresol
Cond. D.	Phenol	77.2	55.0	22.9	139	46	50.0	22.0	38.8	106	26.1		58.3	Phenol
	Cresol	93	37.3	46	64	47	20	7.9*	65	47	35.6		46.3	Cresol
Transverse S/T														
Cond. B.	Phenol	57	51	40.5	51.5	50	45.5	47.5	41.5	56.5	38.5		48.0	Phenol
	Cresol	76.1	122.7	87.4	60.1	92.3	72.4	42.4	88.4	48.9	57.7		74.8	Cresol
Cond. D.	Phenol	5.00	4.4	4.13	5.5	4.6	4.0	5.3	6.00	4.75	6.6		5.03	Phenol
	Cresol	6.4	8.7	11.2	6.8	47.4	4.6	6.3	6.9	7.9	6.7		7.3	Cresol
Transverse S/by/S														
Cond. B.	Phenol	71.7	48.3	25.0	46.7	53	30.8	42.5	44.2	68.3	15*		44.6	Phenol
	Cresol	53.9	55.2	54.2	37.9	72.6	26.4	21.9	67.4	83.7	41.2		51.4	Cresol
Dielectric Strength Transverse S/by/S														
Cond. D.	Phenol	4.67	4.2	4.0	5.5	3.8	2.0*	2.5	3.67	4.83	3.0	Volts/Mil	3.82	Phenol
	Cresol	4.6	5.72	6.8	5.2	6.4	3.1	2.5	4.6	5.54	4.0	"	4.85	Cresol
Impact Strength Lengthwise Face														
Cond. B.	Phenol	4.15	3.69*	8.65	6.14	4.57	5.79	3.25*	5.70	4.13	7.97	Ft.lbs/in.Wd.	5.40	Phenol
	Cresol	3.82	3.73*	4.5	6.75	5.2	6.83	7.38	6.24	5.95	8.06	"	5.86	Cresol
Cond. D.	Phenol	4.64*	3.69*	8.73	6.63	5.53	6.13	3.89*	5.87	4.32*	8.79	"	5.82	Phenol
	Cresol	4.74*	5.39	5.4	5.84	6.43	7.59	8.00	5.53	5.9	6.76	"	6.08	Cresol
Cond. E.	Phenol	5.08	4.45*	9.60	7.98	5.76	6.46	6.30	6.97	5.26	5.73	"	6.36	Phenol
	Cresol	5.03	6.08	6.4	6.11	6.30	6.93	8.23	7.45	6.4	7.59	"	6.65	Cresol
Lengthwise Side														
Cond. B.	Phenol	3.26	2.10*	4.83	3.30	2.39	3.16	2.31	2.98	3.36	4.46	"	3.12	Phenol
	Cresol	2.34	2.99	3.4	3.94	3.6	5.35	4.87	3.72	3.6	4.81	"	3.86	Cresol
Cond. D.	Phenol	3.46	2.42*	5.39	3.88	2.63*	3.18*	2.60*	3.23*	2.48*	3.97	"	3.32	Phenol
	Cresol	3.27	3.82	3.0*	3.71	3.76	5.37	4.86	3.46	4.7	4.69	"	4.06	Cresol
Cond. E.	Phenol	3.93	2.56*	5.42	4.53	3.08*	3.62	4.21	3.57	2.83*	2.65*	"	3.64	Phenol
	Cresol	4.34	5.12	4.3	3.96	4.25	6.02	5.60	4.55	4.45	5.28	"	4.79	Cresol
Crosswise Face	Phenol	9.28	3.68*	3.96	2.87*	4.99	5.10	4.42	2.21*	3.96	4.87	"	4.53	Phenol
Cond. B.	Cresol	3.82	3.73*	4.5	6.75	6.8	6.83	7.38	6.24	5.6	8.06	"	5.97	Cresol
Cond. D.	Phenol	8.84	4.52*	4.32*	3.40*	4.77	4.86	5.67	2.26*	4.27*	5.28	"	4.82	Phenol
	Cresol	4.74*	5.39	5.4	5.84	6.49	7.59	8.00	5.53	5.0	6.76	"	6.07	Cresol
Cond. E.	Phenol	12.39	4.37*	4.46*	3.80*	5.40	6.09	9.53	2.56*	5.04	3.46*	"	5.71	Phenol
	Cresol	5.03	6.08	6.4	6.11	7.17	6.93	8.23	7.45	5.9	7.59	"	6.69	Cresol

	Cresol	4.34	5.12	4.3	3.96	4.25	6.02	5.60	4.55	4.45	5.28	"	4.79	Cresol
Crosswise Face														
Cond. B.	Phenol	9.28	3.68*	3.96	2.87*	4.99	5.10	4.42	2.21*	3.96	4.87	"	4.53	Phenol
	Cresol	3.82	3.73*	4.5	6.75	6.8	6.83	7.38	6.24	5.6	8.06	"	5.97	Cresol
Cond. D.	Phenol	8.84	4.52*	4.32*	3.40*	4.77	4.86	5.67	2.26*	4.27*	5.28	"	4.82	Phenol
	Cresol	4.74*	5.39	5.4	5.84	6.49	7.59	8.00	5.53	5.0	6.76	"	6.07	Cresol
Cond. E.	Phenol	12.39	4.37*	4.46*	3.80*	5.40	6.09	9.53	2.56*	5.04	3.46*	"	5.71	Phenol
	Cresol	5.03	6.08	6.4	6.11	7.17	6.93	8.23	7.45	5.9	7.59	"	6.69	Cresol
Crosswise Side														
Cond. B.	Phenol	4.70	2.44	3.00	1.88*	2.34	2.85	2.37	1.32*	2.30	2.52	"	2.57	Phenol
	Cresol	2.34	2.99	3.4	3.94	3.62	5.35	4.87	3.72	3.68	4.81	"	3.87	Cresol
Cond. D.	Phenol	4.81	2.56*	3.26	2.05*	2.60*	3.06*	2.88*	1.35*	2.58*	2.33*	"	2.73*	Phenol
	Cresol	3.27	3.82	3.0*	3.71	4.14	5.37	4.86	3.46	5.0	4.69	"	4.13	Cresol
Cond. E.	Phenol	6.75	2.75*	3.36	2.27*	2.97*	3.36	4.48	1.66*	2.91*	1.52*	"	3.20	Phenol
	Cresol	4.34	5.12	4.3	3.96	3.93	6.02	5.60	4.55	4.48	5.28	"	4.76	Cresol
Flexural Strength														
Lengthwise Face														
Cond. A.	Phenol	15,610*	19,830	19,530	21,790	19,850	19,100	24,000	26,690	18,710*	19,500	p.s.i.	19,941	Phenol
	Cresol	19,870	---	---	19,600	---	---	---	19,100	25,600	---	"	21,043	Cresol
Cond. B.	Phenol	16,580*	19,020	19,480	22,790	21,890	18,930*	24,250	27,360	19,360	20,100	"	20,976	Phenol
	Cresol	19,500	21,466	30,100	20,500	24,950	30,633	29,233	20,100	24,200	24,716	"	24,540	Cresol
Cond. D.	Phenol	17,860*	19,300	16,800*	21,810	20,320	18,540	23,030	25,690	18,640	19,700	"	20,169	Phenol
	Cresol	20,000	21,850	27,000	19,500	27,800	31,133	26,700	18,100	23,800	21,066	"	23,695	Cresol
Cond. E.	Phenol	17,170	17,770	17,580	20,890	19,270	19,590	20,380	25,330	17,900	19,000	"	19,488	Phenol
	Cresol	19,100	19,050	25,100	17,500	24,750	29,966	27,233	16,800	26,800	23,750	"	23,005	Cresol
Lengthwise Side														
Cond. A.	Phenol	16,590*	18,620*	17,210*	19,950	19,080	18,540*	23,000	26,760	18,010*	20,700	"	19,846	Phenol
	Cresol	20,530	---	---	19,250	---	---	---	20,900	22,600	---	"	20,820	Cresol
Cond. B.	Phenol	17,390*	18,770*	17,450*	22,080	21,320	19,020	20,810	25,110	18,560*	21,000	"	20,151	Phenol
	Cresol	20,400	20,500	27,700	18,900*	23,500	29,000	30,300	22,750	22,500	23,050	"	23,860	Cresol
Cond. D.	Phenol	17,740*	19,130	17,210*	22,620	21,170	20,300	20,470	25,270	18,790*	20,200	"	20,290	Phenol
	Cresol	20,300	21,400	27,000	19,000	25,700	29,850	26,100	22,950	24,600	19,200	"	23,610	Cresol
Cond. E.	Phenol	17,870	17,150	16,590	21,060	19,210	18,770	19,850	25,540	17,160	19,700	"	19,290	Phenol
	Cresol	20,500	17,450	25,500	16,100	21,700	28,350	26,025	19,450	25,300	24,625	"	22,500	Cresol
Crosswise Face														
Cond. A.	Phenol	16,300*	22,100	18,720*	15,420*	19,370	19,560	20,840	18,840*	18,560*	16,900*	"	18,661*	Phenol
	Cresol	19,870	---	---	19,600	---	---	---	19,100	25,600	---	"	21,043	Cresol
Cond. B.	Phenol	17,210*	22,600	19,190	17,490*	21,450	19,690	20,940	17,380*	19,290	16,700*	"	19,194	Phenol
	Cresol	19,500	21,466	30,100	20,500	26,000	30,633	29,233	20,100	24,200	24,716	"	24,645	Cresol
Cond. D.	Phenol	18,400	22,160	17,740*	16,500*	19,910	19,470	19,020	16,970*	19,210	15,800*	"	18,518	Phenol
	Cresol	20,000	21,850	27,000	19,500	28,600	31,133	26,700	18,100	23,800	21,066	"	23,775	Cresol
Cond. E.	Phenol	17,210	20,110	17,770	16,350*	18,560	19,230	17,620	16,130*	17,310	14,200*	"	17,449	Phenol
	Cresol	19,100	19,050	25,100	17,500	26,400	29,966	27,233	16,800	26,800	23,750	"	23,170	Cresol
Crosswise Side														
Cond. A.	Phenol	17,280*	21,310	17,100*	15,400*	18,820*	18,730*	18,680*	17,100*	18,470*	14,900*	"	17,784*	Phenol
	Cresol	20,530	---	---	19,200	---	---	---	20,900	22,600	---	"	20,808	Cresol
Cond. B.	Phenol	17,750*	21,410	18,000*	17,130*	20,590	19,110	19,180	16,160*	18,430*	15,600*	"	18,336*	Phenol
	Cresol	20,400	20,500	27,700	18,900*	23,350	29,000	30,300	22,750	22,500	23,050	"	23,845	Cresol
Cond. D.	Phenol	18,090*	21,750	17,430*	17,240*	20,730	20,150	17,760*	15,880*	18,840*	15,400*	"	18,327*	Phenol
	Cresol	20,300	21,400	27,000	19,000	25,050	29,850	26,100	22,950	24,600	19,200	"	23,545	Cresol
Cond. E.	Phenol	18,240	19,860	15,900*	16,220	19,220	18,860	16,260	16,910	17,070	14,300*	"	17,284	Phenol
	Cresol	20,500	17,450	25,500	16,100	23,300	28,350	26,025	19,450	25,300	24,625	"	22,660	Cresol
Compressive Strength														
Face														
Cond. A.	Phenol	30,530*	42,450	36,230*	41,710	41,460	45,260	41,300	45,190	40,290	32,000*	"	39,642	Phenol
	Cresol	47,500	48,966	44,200	39,650	44,800	47,067	45,100	39,400*	46,000	43,666	"	44,635	Cresol
Cond. B.	Phenol	32,580*	42,220	36,300	40,790	41,840	44,650	38,190	45,270	42,790	33,800	"	39,843	Phenol
	Cresol	43,070	45,533	39,260	33,460*	42,000	46,533	44,433	41,500	44,600	40,866	"	42,126	Cresol
Cond. D.	Phenol	30,050*	37,980	32,400*	38,030	37,160	39,380	31,320*	40,980	38,160	23,000*	"	34,844	Phenol
	Cresol	39,900	41,300	38,600	39,930	40,000	37,633	36,633	36,800	38,700	34,566	"	38,406	Cresol
Cond. E.	Phenol	29,840*	39,860	33,720	37,890	37,830	39,710	31,880	42,820	39,270	29,500*	"	32,232	Phenol
	Cresol	41,200	40,766	38,600	39,360	40,700	40,100	36,266	38,900	38,500	30,566	"	38,296	Cresol
Side														
Cond. A.	Phenol	24,690	27,900	28,550	28,040	27,670	25,850	23,940	29,450	27,590	16,300*	"	25,998	Phenol
	Cresol	29,700	28,400	28,300	23,750	30,250	26,100	21,500	25,000	29,150	28,900	"	26,905	Cresol

Lengthwise Side															
Cond. B.	Phenol	3.26	2.10*	4.83	3.30	2.39	3.16	2.31	2.98	2.36	4.81	"	3.86	Cresol	
	Cresol	2.34	2.99	3.4	3.94	3.6	5.35	4.87	3.72	3.6	3.97	"	3.32	Phenol	
Cond. D.	Phenol	3.46	2.42*	5.39	3.88	2.63*	3.18*	2.60*	3.23*	2.48*	4.69	"	4.06	Cresol	
	Cresol	3.27	3.82	3.0*	3.71	3.76	5.37	4.86	3.46	4.7		"	3.64	Phenol	
Cond. E.	Phenol	3.93	2.56*	5.42	4.53	3.08*	3.62	4.21	3.57	2.83*	2.65*	"	4.79	Cresol	
	Cresol	4.34	5.12	4.3	3.96	4.25	6.02	5.60	4.55	4.45	5.28	"	4.53	Phenol	
Crosswise Face	Phenol	9.28	3.68*	3.96	2.87*	4.99	5.10	4.42	2.21*	3.96	4.87	"	5.97	Cresol	
Cond. B.	Cresol	3.82	3.73*	4.5	6.75	6.8	6.83	7.38	6.24	5.6	8.06	"	4.82	Phenol	
Cond. D.	Phenol	8.84	4.52*	4.32*	3.40*	4.77	4.86	5.67	2.26*	4.27*	5.28	"	6.07	Cresol	
	Cresol	4.74*	5.39	5.4	5.84	6.49	7.59	8.00	5.53	5.0	6.76	"	5.71	Phenol	
Cond. E.	Phenol	12.39	4.37*	4.46*	3.80*	5.40	6.09	9.53	2.56*	5.04	3.46*	"	6.69	Cresol	
	Cresol	5.03	6.08	6.4	6.11	7.17	6.93	8.23	7.45	5.9	7.59	"			
Crosswise Side													2.57	Phenol	
Cond. B.	Phenol	4.70	2.44	3.00	1.88*	2.34	2.85	2.37	1.32*	2.30	2.52	"	3.87	Cresol	
	Cresol	2.34	2.99	3.4	3.94	3.62	5.35	4.87	3.72	3.68	4.81	"	2.73*	Phenol	
Cond. D.	Phenol	4.81	2.56*	3.26	2.05*	2.60*	3.06*	2.88*	1.35*	2.58*	2.33*	"	4.13	Cresol	
	Cresol	3.27	3.82	3.0*	3.71	4.14	5.37	4.86	3.46	5.0	4.69	"	3.20	Phenol	
Cond. E.	Phenol	6.75	2.75*	3.36	2.27*	2.97*	3.36	4.48	1.66*	2.91*	1.52*	"	4.76	Cresol	
	Cresol	4.34	5.12	4.3	3.96	3.93	6.02	5.60	4.55	4.48	5.28	"			
Flexural Strength															
Lengthwise Face															
Cond. A.	Phenol	15,610*	19,330	19,530	21,790	19,850	19,100	24,000	26,690	18,710*	19,500	p.s.i.	19,941	Phenol	
	Cresol	19,870	---	---	19,600	---	---	---	19,100	25,600	---	"	21,043	Cresol	
Cond. B.	Phenol	16,580*	19,020	19,480	22,790	21,890	18,930*	24,250	27,360	19,360	20,100	"	20,976	Phenol	
	Cresol	19,500	21,466	30,100	20,500	24,950	30,633	29,233	20,100	24,200	24,716	"	24,540	Cresol	
Cond. D.	Phenol	17,860*	19,300	16,800*	21,810	20,320	18,540	23,030	25,690	18,640	19,700	"	20,169	Phenol	
	Cresol	20,000	21,850	27,000	19,500	27,800	31,133	26,700	18,100	23,800	21,066	"	23,695	Cresol	
Cond. E.	Phenol	17,170	17,770	17,580	20,890	19,270	19,590	20,380	25,330	17,900	19,000	"	19,488	Phenol	
	Cresol	19,100	19,050	25,100	17,500	24,750	29,966	27,233	16,800	26,800	23,750	"	23,005	Cresol	
Lengthwise Side															
Cond. A.	Phenol	16,590*	18,620*	17,210*	19,950	19,080	18,540*	23,000	26,760	18,010*	20,700	"	19,846	Phenol	
	Cresol	20,530	---	---	19,250	---	---	---	20,900	22,600	---	"	20,820	Cresol	
Cond. B.	Phenol	17,390*	18,770*	17,450*	22,080	21,320	19,020	20,810	25,110	18,560*	21,000	"	20,151	Phenol	
	Cresol	20,400	20,500	27,700	18,900*	23,500	29,000	30,300	22,750	22,500	23,050	"	23,860	Cresol	
Cond. D.	Phenol	17,740*	19,130	17,210*	22,820	21,170	20,300	20,470	25,270	18,790*	20,200	"	20,290	Phenol	
	Cresol	20,300	21,400	27,000	19,000	25,700	29,850	26,100	22,950	24,800	19,200	"	23,610	Cresol	
Cond. E.	Phenol	17,870	17,150	16,590	21,080	19,210	18,770	19,850	25,540	17,160	19,700	"	19,290	Phenol	
	Cresol	20,500	17,450	25,500	16,100	21,700	28,350	26,025	19,450	25,300	24,625	"	22,500	Cresol	
Crosswise Face															
Cond. A.	Phenol	16,300*	22,100	18,720*	15,420*	19,370	19,560	20,840	18,840*	18,560*	16,900*	"	18,661*	Phenol	
	Cresol	19,870	---	---	19,600	---	---	---	19,100	25,600	---	"	21,043	Cresol	
Cond. B.	Phenol	17,210*	22,600	19,190	17,490*	21,450	19,690	20,940	17,380*	19,290	16,700*	"	19,194	Phenol	
	Cresol	19,500	21,466	30,100	20,500	26,000	30,633	29,233	20,100	24,200	24,716	"	24,645	Cresol	
Cond. D.	Phenol	18,400	22,160	17,740*	16,500*	19,910	19,470	19,020	16,970*	19,210	15,800*	"	18,518	Phenol	
	Cresol	20,000	21,850	27,000	19,500	28,600	31,133	26,700	18,100	23,800	21,066	"	23,775	Cresol	
Cond. E.	Phenol	17,210	20,110	17,770	16,350*	18,560	19,230	17,620	16,130*	17,310	14,200*	"	17,449	Phenol	
	Cresol	19,100	19,050	25,100	17,500	26,400	29,966	27,233	16,800	26,800	23,750	"	23,170	Cresol	
Crosswise Side															
Cond. A.	Phenol	17,280*	21,310	17,100*	15,400*	18,820*	18,730*	18,680*	17,100*	18,470*	14,900*	"	17,784*	Phenol	
	Cresol	20,530	---	---	19,200	---	---	---	20,900	22,600	---	"	20,808	Cresol	
Cond. B.	Phenol	17,750*	21,410	18,000*	17,130*	20,590	19,110	19,180	16,160*	18,430*	15,600*	"	18,336*	Phenol	
	Cresol	20,400	20,500	27,700	18,900*	23,350	29,000	30,300	22,750	22,500	23,050	"	23,845	Cresol	
Cond. D.	Phenol	18,090*	21,750	17,430*	17,240*	20,730	20,150	17,760*	15,880*	18,840*	15,400*	"	18,327*	Phenol	
	Cresol	20,300	21,400	27,000	19,000	25,050	29,850	26,100	22,950	24,600	19,200	"	23,545	Cresol	
Cond. E.	Phenol	18,240	19,860	15,900*	16,220	19,220	18,860	16,260	16,910	17,070	14,300*	"	17,284	Phenol	
	Cresol	20,500	17,450	25,500	16,100	23,300	28,350	26,025	19,450	25,300	24,625	"	22,660	Cresol	
Compressive Strength															
Face															
Cond. A.	Phenol	30,530*	42,450	36,230*	41,710	41,460	45,260	41,300	45,190	40,290	32,000*	"	39,642	Phenol	
	Cresol	47,500	46,966	44,200	39,650	44,800	47,067	45,100	39,400*	46,000	43,666	"	44,635	Cresol	
Cond. B.	Phenol	32,580*	42,220	36,300	40,790	41,840	44,650	38,190	45,270	42,790	33,800	"	39,843	Phenol	
	Cresol	43,070	45,533	39,260	33,460*	42,000	46,533	44,433	41,500	44,800	40,866	"	42,126	Cresol	
Cond. D.	Phenol	30,050*	37,980	32,400*	38,030	37,160	39,380	31,320*	40,980	38,160	23,000*	"	34,844	Phenol	
	Cresol	39,900	41,300	38,600	39,930	40,000	37,633	36,633	36,800	38,700	34,566	"	38,406	Cresol	
Cond. E.	Phenol	29,840*	39,860	33,720	37,890	37,830	39,710	31,880	42,820	39,270	29,500*	"	32,232	Phenol	
	Cresol	41,200	40,766	36,600	39,360	40,700	40,100	36,266	38,900	38,500	30,566	"	38,296	Cresol	
Side															
Cond. A.	Phenol	24,690	27,900	28,550	28,040	27,670	25,850	23,940	29,450	27,590	16,300*	"	25,998	Phenol	
	Cresol	29,700	26,400	28,300	23,750	30,250	26,100	21,500	25,000	29,150	28,900	"	26,905	Cresol	
				33,500	27,400	26,980	24,550	18,770*	26,650	29,120	20,000*	"	25,978	Phenol	
								21,450*	25,100	29,700	24,900	"	25,993	Cresol	

	Cresol	43,070	45,533	39,260	33,460*	42,000	46,533	44,433	41,500	44,600	40,866	"	42,126	Cresol
Cond. D.	Phenol	30,050*	37,980	32,400*	36,030	37,160	39,380	31,320*	40,980	36,160	23,000*	"	34,844	Phenol
	Cresol	39,900	41,300	38,600	39,930	40,000	37,833	36,633	36,800	38,700	34,566	"	38,406	Cresol
Cond. E.	Phenol	29,840*	39,860	33,720	37,890	37,830	39,710	31,880	42,820	39,270	29,500*	"	32,232	Phenol
	Cresol	41,200	40,766	36,600	39,360	40,700	40,100	36,266	38,900	38,500	30,566	"	38,296	Cresol
Side														
Cond. A.	Phenol	24,690	27,900	28,550	28,040	27,670	25,850	23,940	29,450	27,590	16,300*	"	25,998	Phenol
	Cresol	29,700	26,400	28,300	23,750	30,250	26,100	21,500	25,000	29,150	28,900	"	26,905	Cresol
Cond. B.	Phenol	21,790	31,010	33,500	27,400	26,980	24,560	18,770*	26,650	29,120	20,000*	"	25,978	Phenol
	Cresol	26,200	24,050	29,350	24,100	29,400	25,675	21,450*	25,100	29,700	24,900	"	25,993	Cresol
Cond. D.	Phenol	23,100	25,590	31,080	25,580	23,030	21,990	19,100	21,590	24,580	12,200*	"	22,784	Phenol
	Cresol	25,300	21,950	25,650	23,200	26,000	25,200	17,100	26,100	24,400	23,125	"	23,803	Cresol
Cond. E.	Phenol	21,620	25,310	30,800	25,350	22,630	21,770	20,200	23,350	26,150	10,500*	"	22,768	Phenol
	Cresol	26,800	22,350	23,900	22,760	25,900	24,475	15,900*	22,900	25,000	21,325	"	23,131	Cresol
Tensile Strength Lengthwise 1/8"														
Cond. A.	Phenol	7,640*	9,360*	11,420	11,570	10,810	10,010	9,490*	13,710	8,850*	13,300	"	10,616	Phenol
	Cresol	9,630	10,014	9,680	12,700	11,340	12,340	12,914	9,075*	---	10,036	"	10,859	Cresol
Cond. B.	Phenol	8,070*	9,490	12,780	11,640	10,150	9,960	9,890	14,960	9,320*	12,700	"	10,896	Phenol
	Cresol	10,110	10,062	9,350	13,220	11,600	11,750	12,580	9,130*	---	10,664	"	10,941	Cresol
Cond. D.	Phenol	8,990*	8,760*	14,180	11,290	11,010	10,540	8,330*	13,530	9,200*	11,200	"	10,703	Phenol
	Cresol	9,530*	12,766	9,930*	13,180	12,000	12,920	12,830	9,605*	---	11,056	"	10,382	Cresol
Cond. E.	Phenol	8,380*	8,450*	11,900	11,410	10,400	10,260	8,040*	13,800	8,230*	13,400	"	10,497	Phenol
	Cresol	10,880	10,936	15,300	11,760	12,250	12,450	12,880	8,550*	---	9,276	"	11,587	Cresol
Lengthwise 1/2"														
Cond. A.	Phenol	9,120*	13,110	10,510	11,760	11,790	10,610	10,380	17,110	10,350	---	"	11,638	Phenol
	Cresol	---	12,310	---	---	---	13,770	---	12,060	11,100	10,036	"	11,855	Cresol
Cond. B.	Phenol	9,440	13,380	10,520	12,070	12,530	10,540	12,230	17,190	10,870	---	"	12,086	Phenol
	Cresol	---	12,800	---	---	---	14,200	---	11,640	12,200	10,664	"	12,301	Cresol
Cond. D.	Phenol	9,780*	12,800	10,480	12,520	12,310	11,530	14,570	16,660	10,840	---	"	12,388	Phenol
	Cresol	---	13,840	---	---	---	13,400	---	12,720	11,500	11,056	"	12,503	Cresol
Cond. E.	Phenol	9,520	11,900	9,930	11,490	11,540	10,140	13,580	16,170	9,640	---	"	11,579	Phenol
	Cresol	---	11,650	---	---	---	13,080	---	9,534	11,880	9,276	"	11,124	Cresol
Crosswise 1/8"														
Cond. A.	Phenol	9,220*	8,060*	10,190	7,870*	10,470	12,460	14,260	9,180*	9,520	8,540*	"	9,957	Phenol
	Cresol	9,630	10,014	9,680	12,700	11,340	12,340	12,914	9,075*	---	10,036	"	10,859	Cresol
Cond. B.	Phenol	9,950	8,840*	10,950	8,020*	10,950	12,670	14,420	9,500	10,490	8,420*	"	10,421	Phenol
	Cresol	10,110	10,062	9,350	13,220	11,600	11,750	12,580	9,130*	---	10,664	"	10,941	Cresol
Cond. D.	Phenol	9,620*	7,660*	13,130	7,650*	10,940	12,720	13,960	8,760*	9,320*	7,920*	"	10,174	Phenol
	Cresol	9,530*	12,766	9,930*	13,180	12,000	12,920	12,830	9,605*	---	11,056	"	10,382	Cresol
Cond. E.	Phenol	9,370	7,530*	11,660	7,390*	10,400	12,360	13,000	8,530*	9,010	8,390*	"	9,794	Phenol
	Cresol	10,880	10,936	15,300	11,760	12,250	12,450	12,880	8,550*	---	9,276	"	11,587	Cresol
Crosswise 1/2"														
Cond. A.	Phenol	9,500	10,110	10,060	8,990*	11,620	10,670	11,550	10,060	11,350	---	"	10,434	Phenol
	Cresol	---	12,310	---	---	---	13,770	---	12,060	11,100	10,036	"	11,855	Cresol
Cond. B.	Phenol	10,250	10,130	10,690	9,090*	12,370	11,220	10,850	10,240	11,370	---	"	10,691	Phenol
	Cresol	---	12,800	---	---	---	14,200	---	11,640	12,200	10,664	"	12,301	Cresol
Cond. D.	Phenol	10,590	10,300	10,250	8,650*	11,970	11,570	11,780	10,140	11,310	---	"	10,729	Phenol
	Cresol	---	13,840	---	---	---	13,400	---	12,720	11,500	11,056	"	12,503	Cresol
Cond. E.	Phenol	10,160	9,840	10,220	8,270*	11,300	11,130	11,050	9,430	10,510	---	"	10,212	Phenol
	Cresol	---	11,850	---	---	---	13,080	---	9,534	11,880	9,276	"	11,124	Cresol
Bonding Strength														
Cond. D.	Phenol	1,790	1,900	2,300	2,220	1,641*	2,020	1,564*	1,710	2,040	1,160*	lbs.	1,835	Phenol
	Cresol	1,840	---	---	2,184	---	---	---	1,715	---	---	"	1,913	Cresol
Cond. E.	Phenol	1,940	1,920	2,130	2,160	1,709	2,030	1,581*	1,750	2,090	1,240*	"	1,855	Phenol
	Cresol	2,115	---	---	2,175	---	---	---	1,751	---	---	"	2,014	Cresol

Note: Wherever an asterisk (*) is shown on the table, this indicates failure to comply with Navy specification requirements.

Type FBM
Cresol versus Phenol
Comparison of Average Values.

In the following discussion there is shown a detailed comparison, test by test, of the average mechanical and electrical properties of the phenol and cresol resin laminates under Type FBM:

(*a*) While the percentage of water absorption and acetone extraction are not covered by the specification and are not, per se, measures of quality of the product, they are indicative of specific formulations and may therefore be utilized as "fingerprints" or "product identity" symbols. The average values are as follows:

	Phenol	*Cresol*
Water Absorption	1.45	1.14
Acetone Extraction	4.90	3.02

(*b*) The average insulation resistance in megohms of both phenol and cresol products meets the specification requirements. That of the cresol resin product in Condition D is considerably higher than that of the phenol product.

	Phenol	*Cresol*
For Condition B	200 +	200* +
For Condition D	1.4	5.04

(*c*) The average dielectric strengths, in volts per mil, of the parallel specimens, Condition A, and all the transverse specimens of the phenol products is much lower than those of the corresponding cresol products.

	Phenol		*Cresol*	
For Conditions	A	D	A	D
Parallel				
s/t	319	94.9	359	86.6
s/by/s	246	58.3	289	46.3

For Conditions	B	D	B	D
Transverse				
s/t	48	5.03	74.8	7.3
s/by/s	44.6	3.82	51.4	4.85

(*d*) The average impact strength of the phenol products is from 4 per cent to 34 per cent lower than that of the corresponding cresol products. In Condition D, crosswise, side, the phenol products failed to meet the specification requirements.

	Phenol			*Cresol*		
For Conditions	B	D	E	B	D	E
Lengthwise						
Face	5.40	5.82	6.36	5.86	6.08	6.65
Side	3.12	3.32	3.64	3.86	4.06	4.79
Crosswise						
Face	4.53	4.82	5.71	5.97	6.07	6.69
Side	2.57	2.73*	3.20	3.87	4.13	4.76

(*e*) In every case the average flexural strength of the phenol products is inferior to that of the cresol products. In four instances the average flexural strength of the phenol products fails to meet the specification requirements. Three of these failures are found in the average values for the crosswise specimens in the side.

	Phenol				*Cresol*			
For Conditions	A	B	D	E	A	B	D	E
Lengthwise								
Face	19,941	20,976	20,169	19,488	21,043	24,540	23,695	23,005
Side	19,846	20,151	20,290	19,290	20,820	23,860	23,610	22,500
Crosswise								
Face	18,661*	19,194	18,518	17,449	21,043	24,645	23,775	23,170
Side	17,784*	18,336*	18,327*	17,284	20,808	23,845	23,545	22,660

(*f*) The average compressive strengths of the phenol products are lower than those of the corresponding cresol products, but the average results in all cases for both materials meet the specification requirements.

For Conditions	*Phenol* A	B	D	E	*Cresol* A	B	D	E
Face	39,642	39,843	34,844	32,232	44,635	42,126	38,406	38,296
Side	25,998	25,987	22,784	22,768	26,905	25,993	23,803	23,131

(*g*) In most cases the average tensile strength of the phenol specimens is somewhat lower than that of the corresponding cresol specimens.

For Conditions	*Phenol* A	B	D	E	*Cresol* A	B	D	E
Lengthwise								
⅛ inch	10,616	10,896	10,703	10,497	10,859	10,941	10,382	11,587
½ inch	11,638	12,086	12,388	11,579	11,855	12,301	12,503	11,124
Crosswise								
⅛ inch	9,957	10,421	10,174	9,794	10,859	10,941	10,382	11,587
½ inch	10,434	10,691	10,729	10,212	11,855	12,301	12,503	11,124

(*h*) The average bonding strength of the phenol products is lower than that of the cresol products.

	Phenol	*Cresol*
Condition D	1835	1913
Condition E	1855	2014

Discussion Covering a Specific Example of Type FBM Laminate, Identified as Product "J".

The following data, taken from the general data breakdown, Table IV for Product "J", are discussed here for emphasis. If one so desired, he could take each of the other nine products and do exactly the same thing. It is believed, however, that Product "J" is fairly representative of the whole lot of Type FBM products. This example will, therefore, serve to emphasize what happens to one specific FBM laminate when an attempt is made to substitute phenol for cresol.

(*a*) While water absorption and acetone extraction values are not of themselves any criterion of quality, and hence are not specified, they are indicative of a change in formulation and in that sense serve only as a "fingerprint", to "identify" the product.

* Does not meet specification requirements.

	Phenol	*Cresol*
Acetone Extraction		
⅛-inch	4.76%	2.29%
½-inch	5.28%	3.14%
Water Absorption (3 inches × 1 inch × ⅛ inch at 25 degrees C. for 48 hours)	1.54%	.91%

(*b*) The dielectric strength of the cresol resin product in volts per mil was found to be lower than that of the phenol resin product under Condition D:

	Phenol	*Cresol*
s/t	159	75.3 volts/mil
s/by/s	106	47

(Both are well above the minimum required by specification)

(*c*) The impact strength of the cresol resin product in foot pounds per inch width was found to be higher than that of the phenol resin product:

	Phenol	*Cresol*
Condition B		
Lengthwise		
Face	4.13	5.95
Side	2.36	3.6
Crosswise		
Face	3.96	5.6
Side	2.30	3.68
Condition D		
Lengthwise		
Face	4.32*	5.9
Side	2.48*	4.7
Crosswise		
Face	4.27*	5.0
Side	2.58*	5.0

	Phenol	*Cresol*
Condition E		
Lengthwise		
Face	5.26	6.4
Side	2.83*	4.8
Crosswise		
Face	5.04	5.9
Side	2.91	4.48

(*d*) The average flexural strength of the cresol resin product was found to be higher than that of the phenol resin product:

	Phenol	*Cresol*
Condition A		
Lengthwise, Face	18,710*	
Crosswise, Face	18,560*	
Average	18,635*	25,600
Lengthwise, Side	18,010*	
Crosswise, Side	18,470*	
Average	18,240	22,600
Condition B		
Lengthwise, Face	19,360	
Crosswise, Face	19,290	
Average	19,325	24,200
Lengthwise, Side	18,560*	
Crosswise, Side	18,430*	
Average	18,495*	22,500
Condition D		
Lengthwise, Face	18,640	
Crosswise, Face	19,210	
Average	18,925	23,800

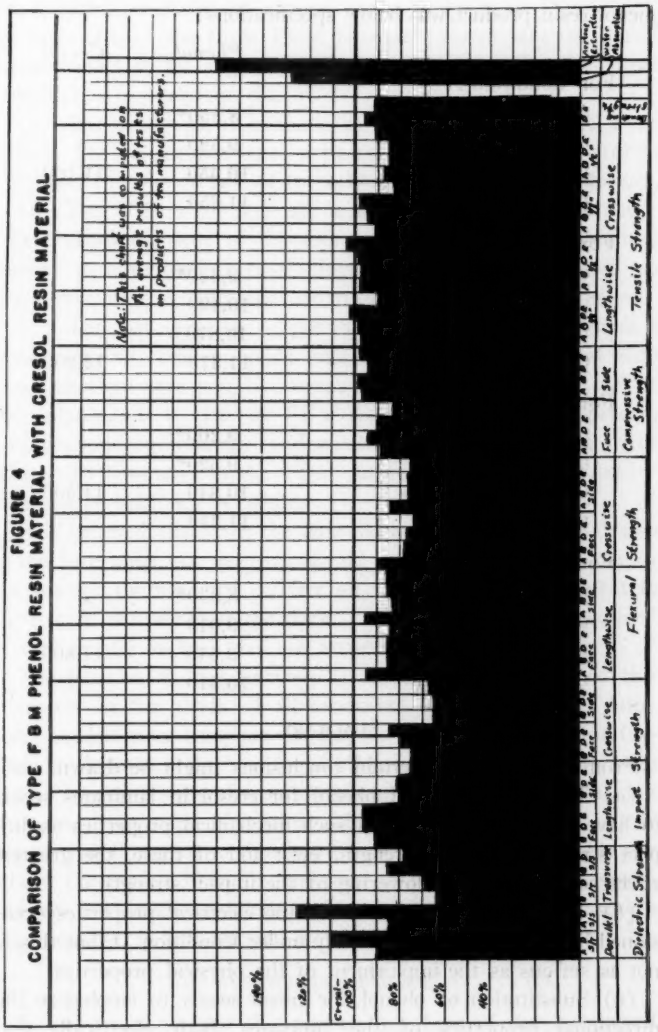
	Phenol	*Cresol*
Lengthwise, Side	18,790*	
Crosswise, Side	18,840*	
Average	18,815	24,600
Condition E		
Lengthwise, Face	17,900	
Crosswise, Face	17,310	
Average	17,605	26,800
Lengthwise, Side	17,160	
Crosswise, Side	17,070	
Average	17,115	25,300

(*e*) The average compressive strength, in pounds per square inch, of samples of the cresol product under Conditions A, B and D was found to be higher than that of the corresponding phenol product:

	Phenol	*Cresol*
Condition A		
Face	40,290	46,000
Side	27,590	29,150
Condition B		
Face	42,790	44,600
Side	29,120	29,700
Condition D		
Face	38,160	38,700
Side	24,580	24,400
Condition E		
Face	39,270	38,500
Side	26,150	25,000

All values are above specification minimums.

(*f*) The tensile strength of the cresol resin product, in pounds per square inch, was found to be greater than that of the phenol


COMPARISON OF TYPE F B M PHENOL RESIN MATERIAL WITH CRESOL RESIN MATERIAL
Note: This chart was compiled on the average results of tests on products of the manufacturer.
140%
120%
Cresol 100%
80%
60%
40%
Dielectric Strength
Impact Strength
Flexural Strength
Compressive Strength
Tensile Strength
Parallel
Transverse
Lengthwise
Crosswise
Flat
Side
Working Variation
Under Variation

resin product. In several instances the tensile strength of the phenol resin product was below specifications:

	Phenol	*Cresol*
For Condition A		
⅛ inch Lengthwise	8,850*	
⅛ inch Crosswise	9,520	
½ inch Lengthwise	10,350	11,100
½ inch Crosswise	11,350	
For Condition B		
⅛ inch Lengthwise	9,320*	
⅛ inch Crosswise	10,490	
½ inch Lengthwise	10,870	
½ inch Crosswise	11,370	12,200
For Condition D		
⅛ inch Lengthwise	9,200*	
⅛ inch Crosswise	9,320*	
½ inch Lengthwise	10,840	11,500
½ inch Crosswise	11,310	
For Condition E		
⅛ inch Lengthwise	8,930*	
⅛ inch Crosswise	9,010	
½ inch Lengthwise	9,640	11,800
½ inch Crosswise	10,510	

SUMMARY.

From the foregoing, certain conclusions might be drawn, viz.:

(*a*) The substitution of phenol for cresol in laminates seems to have the greatest effect on such mechanical properties as impact strength, flexural strength, etc.; and of these, the greatest effect seems to be in a lowering of the impact strength.

(*b*) There is some reduction in the electrical properties occasioned by substitution, particularly under Condition D, but this is not as serious as the impairment of the physical properties.

(*c*) Substitution of phenol for cresol seems to emphasize the directional properties of the laminates, both electrically and mechanically.

(*d*) Of the four types of laminates tested, the one in which the greatest possibility of success seems to lie is in Type PBM. In fact, one of the three PBM laminates tested met the Naval requirements in all respects, and the other two offered distinct possibilities of early success.

(*e*) The next type of laminate in order of possibility is Type FBG. The substitution here appears to have been successful in one case, and one or two of the others seem to have possibilities.

(*f*) The Type FBE laminate is about third in order of possibility; about one-half of the total number of brands submitted seemed to have distinct possibilities along this line, although no one formulation actually came up to full specification requirements.

(*g*) The last in order of possibilities, but the one in which a greater saving could be made than in any of the others, if such a substitution were possible, seems to lie in Type FBM. All of the submissions to date on FBM seem to lie far below present specification requirements, and much more work will have to be done with laminates in the FBM category before such substitution can be held as a possibility.

It is believed that with the data shown and conclusions drawn in the foregoing, our next try should insure a greater measure of success for the next try. After all, these were all somewhat in the nature of "shots in the dark", and it is not to be wondered at that greater success was not attained in the initial attempt.

The purpose of this analysis is to place information of this character in the hands of all producers of phenolic resin laminates so that more complete use may be made of the data for further development. Each of the exhibitors has been furnished with a copy of the results of tests on his own particular material, but none has seen what the other fellow has accomplished. It is hoped that this general breakdown of test data will enable the whole Laminated Phenolic Industry to profit by such a study, and yet not break confidence with any individual. If it serves that purpose, it will be well worthwhile.

ACKNOWLEDGEMENT.

It was necessary for the various members of the Laminated Phenolics industry to prepare many new formulations quickly and

in a high spirit of cooperation. Full acknowledgement is hereby made of the Industry's help in making this study possible. Acknowledgement is also made of the suggestions offered by various members of the War Production Board and of the Office of Procurement and Material, Navy Department. While these data do not show that any high degree of success has been attained in the program thus far, they may give birth to further ideas as to how this may be accomplished.

The information contained in this article is based upon tests conducted under the Bureau's direction at the Material Laboratory, U. S. Navy Yard, New York, N. Y. The data presented herein are but a fraction of those obtained by the Material Laboratory in this connection; the Laboratory is doing an excellent job of plastics testing, and full acknowledgement is hereby made of the Laboratory's contribution to this program.

The compilation of these data, from various Laboratory reports, their coordination and tabulation, represent the work of Miss Margaret Lynn, Junior Physicist of the Electrical Group, Standards and Tests Section, Bureau of Ships, and grateful acknowledgement of her assistance is hereby made. And finally, I am indebted to my Secretary, Mrs. Kathryn Kinney, for her assistance in the planning, the general coordination and editorial presentation of this report.

NOTES.

INDEX TO NOTES.

QUICK STARTING OF STEAM TURBINES.
—Brown Boveri Review, August, 1942.

ELECTRONIC MOTOR CONTROL.
—General Electric Review, April, 1943.

THE EXTREME PROPERTIES OF MATTER.
—Engineering (London), February 5, 12 and 19, 1943.

OPERATION AND CARE OF BOILER CONTROL SYSTEMS.
—The Nautical Gazette, February, 1943.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

Report on 1200-Pound Reheat Marine Installation.
—Marine Engineer, May, 1943.

Powder Metallurgy: Its Products and Their Various Applications.
—NE Coast Institution of Engineers and Shipbuilders, February, 1943.

Sampling and Quality Control.
—Science, March 5, 1943.

QUICK STARTING OF STEAM TURBINES.

This article by K. Frey is taken from The Brown Boveri Review, August, 1942. Mr. Frey's article explains how steam turbines may be put into service both quickly and safely, even with high steam temperatures, provided the machines are suitably designed, and provided proper attention is given to them when stopping, during the shut-down period and upon restarting.

I. General.

QUICK STARTING.

In addition to the other operating characteristics of the individual turbines of a station, the possibility of quick starting plays an important part. Although in the general case plenty of time is available for warming-up and running-up a turbo-set, conditions may arise which make quick putting into service a necessity. This is a question which requires the cooperation of both designer and operator. The latter may rightly expect to obtain a reliable machine, but on the other hand the turbine maker may with equal right expect the turbine designed by him to be operated in a suitable manner. Increasing pressures and temperatures have contributed to bring this problem more and more into the foreground; because high temperatures mean increased temperature differences, and hence they require that careful attention be given both to the design and to the method of operation. In the following, the considerations referring to this important question are set down in order to enable the operating engineer to obtain a better understanding of the design of his machine, and to make it easier for him to handle it in the right manner.

DESIGN CONSIDERATIONS.

The above-mentioned temperature differences between the individual parts of the turbine, through which a stream of expanding steam is flowing, require first and foremost that wall thicknesses shall as far as possible be kept equal. The unavoidable variations of sections and concentrations of metal such as occur for instance at flanges, must be reduced to a minimum, in order to avoid delays in warming up and in cooling down when load changes, and thereby to keep temperature differences small.

In the case of high-pressure turbines it is advantageous to locate the nozzles in separate nozzle chests, in accordance with Figure 1, and to build these into the turbine casing proper. The material of the casing has then only to be chosen suitable for withstanding the reduced temperature and the lower pressure of the first wheel chamber. In order to obtain a simple connection of the various parts without massing the metal, the nozzle boxes of the casing are welded to corresponding necks of the casing, and also the valve casings. The flange joints hitherto used are then done away with, and with them all their disadvantages. The dimensions of the unavoidable flanges must be fixed on the basis of a minimum use of material, the distribution of which has to be carefully considered. For this reason it is necessary to allow for the resulting differences of expansion by deliberately increasing the length of the bolts in accordance with Figure 2. Increasing the bolt length and the use of bushes between the casing flange and nut enables the percentage expansion of the bolts to be reduced to a fraction of that otherwise obtaining, thus ensuring that it remains definitely within the elastic limit. Permanent extension of the bolt shanks, and the consequent leakage at the flange, are thus avoided. Because a simultaneous warming-up of the bolts with the flanges tends to keep the tensile stresses low, it is important that the bolts shall be screwed directly into one of the flanges; simple through-bolts should not be employed.

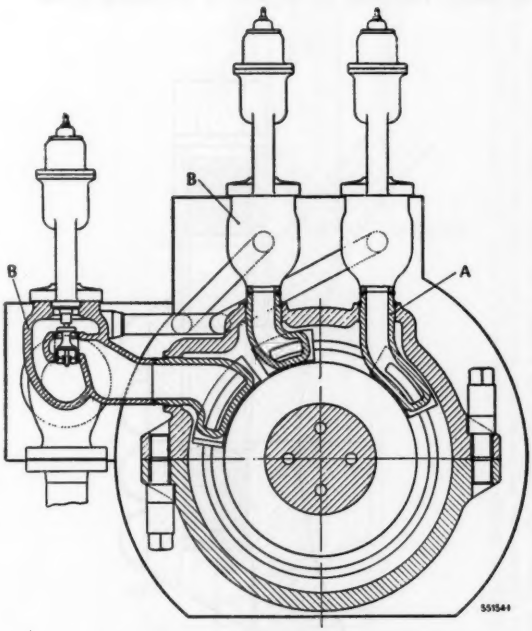


Fig. 1. — Section through the admission parts showing the welded-in nozzle boxes and the welded valve casings.

A. Nozzle boxes B. Valve casings.

Welding replaces flange connections.

In the case of high temperature turbines, it has in addition been found advantageous to heat the flanges externally, in order to obtain a rapid equalization of the temperatures over the entire flange portion. Figure 2 shows such a flange warming arrangement, which is constituted by two welded-on tube halves through which live steam is passed. Since live steam is employed, it is always possible to obtain any desired heating temperatures by correspondingly regulating the pressure in the heating device.

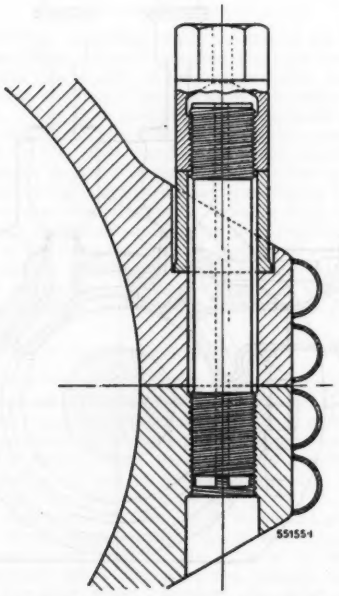


Fig. 2. — Section through a flange joint. Extended bolts and expansion collars between the casing flange and the nut take care of the unavoidable differences in expansion. Half-tubes welded on to the flanges enable the latter to be subjected to additional external heating and thereby to obtain uniform expansion.

The general design of the casing must in the first place be such as to ensure uniform expansion during warming-up. For example, in impulse turbines care has to be taken to make an allowance for expansion of the diaphragms inside the casing. In the case of reaction turbines having an impulse wheel in front of the reaction blading, sudden changes of section between impulse wheel casing and reaction part must be avoided. It is also advantageous to locate the first part of the reaction blading on a separate blade carrying ring, mounted in the casing, as shown in Figure 3.

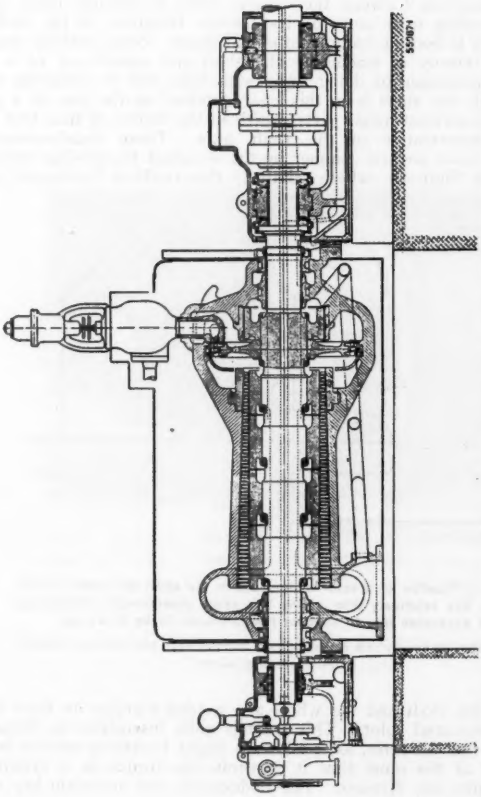


Fig. 3. — Longitudinal section through a primary turbine with welded-in nozzle boxes and welded-on valve casings, and separate blade-carrying ring for the first guide blades. Balancing piston, impulse wheel and moving blade drums of the reaction part are welded to the shaft by means of lip-welds.

The large temperature difference of such superheated steam turbines require also that corresponding attention be given to the design of the rotor. Wheels or drums carrying blading shrunk on the shaft warm up more quickly during starting than the shaft does, as the latter is practically not in contact with the steam; they also cool down more rapidly, especially when the load is suddenly dropped. It is no wonder, therefore, that the mechanical connection between these parts tends to become loose after a certain time, leading to a more or less severe vibration of the shaft, and causing the keys to become hammered out of shape. Some turbine designers have sought a remedy in machining the shaft and wheels out of a single forging. The advantage of doing away with hubs and of obtaining a solid metal joint with the shaft is in this case obtained at the cost of a poorer forging of the innermost metal parts, which in the course of time may result in permanent deformation of the shaft axis. These disadvantages are avoided in the most positive manner by the so-called lip-welding process in accordance with Figure 4, where relatively thin resilient lip-shaped projec-

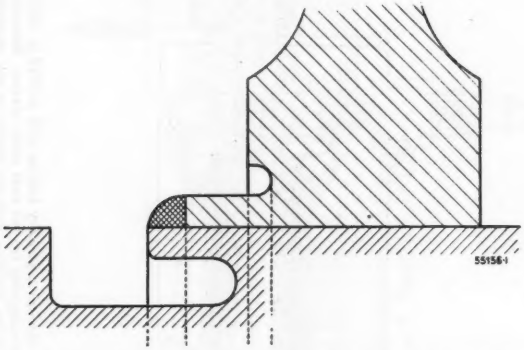


Fig. 4. — Fixation of a rotor component to the shaft by means of lip-welding. The relatively thin joining lips allow considerable differences in expansion due to unequal temperatures to be taken up.

Lip welding of the wheels replaces keys and keyways and prevents wheels from becoming loose.

tions on both the shaft and the wheel are welded together to form a continuous circumferential joint. This weld is quite insensitive to changes of either shaft or hub diameter, as it allows a slight breathing motion between the two parts; at the same time it transmits the torque in a symmetrical manner with quite low stresses. The undesirable and uncertain key fixings are, in this way, completely done away with.

The same excellent characteristics with regard to insensitivity to temperature are possessed by the welded rotors shown in Figure 5, which are built up by welding together individual rotor parts at their outer periphery. The location of the welds at the periphery results in only very low stresses in the weld metal. The construction enables reliable rotors to be built, avoiding all the disadvantages of the design hitherto employed. As in the case of the above-mentioned lip-weld, all key fixings, and with them the danger of loose shaft parts, are done away with. This construction has all the advan-

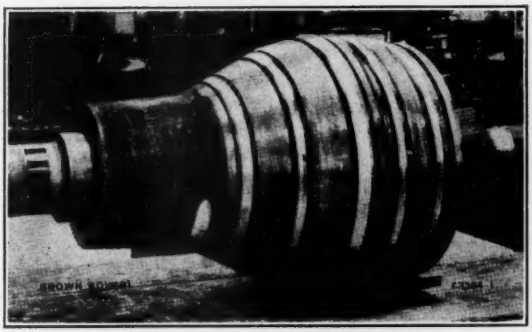


FIGURE 5.—A TURBINE SPINDLE BUILT UP OF SEPARATE ROTOR PARTS WELDED TOGETHER. THE ELECTRODE MATERIAL SPECIALLY SELECTED FOR THE WELD SHOWS UP AS LIGHT ANNULAR MARKINGS BETWEEN THE INDIVIDUAL ROTOR PARTS.

The Welded Rotor Is Built Up of Soundly Forged Components Which Can Be Given Simple Shapes.

tages of a shaft made out of a single forging without its disadvantages, namely, high weight, poor forging of the innermost metal and local overstressing due to temperature and expansion differences. Complete freedom exists in regard to the shape given to the component parts, which can then be made such as to distribute the stress uniformly, to which is added the advantage of increased security resulting from the possibility of perfect forging and heat treatment of all parts of each component.

OPERATIONAL CONSIDERATIONS.

Although the above-mentioned design precautions make a high temperature machine stand up well to quick starting and sudden load changes, it is advisable to consider briefly the effects of such changes, for turbines are expensive objects, and it is certainly well worth while giving them proper attendance and care. Because temperature differences inside the casing and the rotor become increasingly great, as the time taken in putting such turbines into service is reduced, the general practice is rightly to allow a liberal amount of time of starting. If, however, because of a sudden outage of some machine, the time for putting into service of another has to be shortened as far as possible, it is important for the operating engineer to know each of his machines thoroughly and to understand perfectly its behavior during the process of putting into service.

When steam is sent into the cold turbine of a unit which is being started, it condenses on the walls of the housing and on the rotor; hence, the maximum temperature which these surfaces can attain, is the saturation temperature corresponding to the pressure of the steam inside the turbine. To know this fact is important, because the steam pressure during putting into service is a definite measure of the attainable and at the same time uniform warming-up temperature. It is, of course, naturally advantageous to speed up the uniform warming-up of condensing turbines as much as possible, and it is therefore correct to effect this warming-up process with a poor vacuum. In addition to this, it is however particularly important that during warming up the shaft shall be driven round by the steam right from the start, even if but slowly, in order that a uniform wetting shall take place of all parts in contact with the steam, so as to avoid temperature differences. For this warming-up process a speed of a few hundred revolutions per minute is sufficient. Its duration depends largely on the size of the turbine, on the thickness of the walls and on the general design characteristics.

When starting-up back-pressure turbines, the valve in the back-pressure line should first be opened, unless an auxiliary supply of live steam at reduced pressure is available for warming up. If the back-pressure line is already under steam pressure, steam will, upon opening the valve, flow back into the turbine. Because in the case of primary turbines, due to the relatively high back-pressure, the saturation temperature is considerably higher than that existing inside condensing turbines, the warming-up temperature is correspondingly increased. This means that considerable temperature differences may occur, and special care must accordingly be taken to avoid warming-up too quickly. It is, therefore, advantageous in this case to open the back-pressure valve at first only slightly, so that the warming-up steam quantity remains small, and the rate of heat supply is kept low. By gradually increasing the opening of the back-pressure valve, the pressure inside the turbine can be slowly increased, and in this manner the warming-up process can be conducted until the full back-pressure is attained. As already insisted upon, it is essential for a uniform warming-up that the shaft shall rotate. Because in this case the warming-up is effected by steam from the back-pressure line, it is necessary to arrange for the shaft to be rotated either by hand or by means of a motor. If a hand turning device is pro-

vided, it is sufficient to rotate the shaft periodically through 180 degrees. The time required for warming-up is largely dependent upon the size and on the design of the turbine, and last but not least, upon the operating temperature.

As soon as the turbine is under full back-pressure, the live steam stop valve can be opened as far as is required, in order that the steam admitted shall cause the shaft to rotate slowly. After this, the steam quantity and the speed are gradually increased as in the case of the condensing turbines, until normal running speed is obtained.

Now and again, when it is possible to make use in some way or other of the reduced pressure exhaust steam, back-pressure and primary turbines may be warmed up by means of live steam. After being thoroughly warmed up—always with slowly rotating shaft—the back-pressure and hence the warming-up temperature may be raised by gradually closing the valve in the auxiliary exhaust line until the normal back-pressure is attained, whereupon the back-pressure valve may be opened. External heating of the flanges, as described above, is of considerable value for back-pressure turbines and especially for primary turbines.

RESTARTING OF TURBINES AFTER A SHORT SHUT-DOWN.

Not only starting after a prolonged shut-down, that is, with the cold machine, but especially restarting after a limited shut-down interval, requires care and understanding. After a turbo-set is shut down, a continuous transfer of heat is effected by steam or air enclosed in the casing from the lower to the upper parts. As has been pointed out by E. A. Kraft[1], due to the increased rate of heat loss of the parts below the shaft axis and the consequent local cooling, a bending may take place of both the shaft and of the casing. It is evident that a bent shaft, upon restarting, will cause unsteady running and under certain circumstances may provoke severe vibration. If at the same time a certain amount of distortion of the casing has taken place, it may even be possible that rubbing may occur upon restarting.

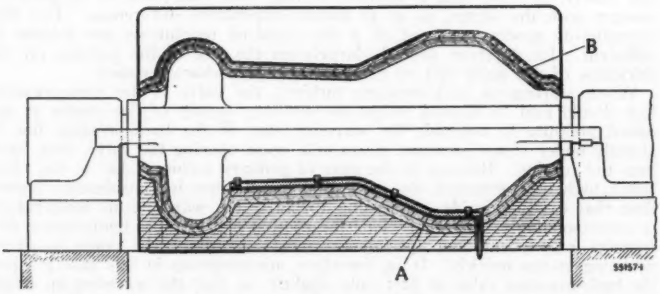


Fig. 6. — Electrical resistance heating along the bottom part of the turbine casing. The more rapid heat loss due to the natural internal heat flow is compensated by means of this additional heating arrangement. For the same reason the insulation of the lower part of the casing is made heavier than that of the upper part.

A. Electrical resistance heating. B. Insulation.

[1] E. A. Kraft, "Die Dampfturbine im Betriebe", Springer 1935, page 201.

There exists, however, a possibility of reducing these distortions to an admissible amount, if not entirely to eliminate them. Already an increase in the thermal insulation of the lower casing half, compared with that of the upper casing half, leads to an appreciable improvement, because the resulting greatly reduced heat loss of the lower half largely compensates the effect of the upward heat flow inside the turbine. With extra high temperatures it is very advantageous to provide a heating arrangement at the lowest part of the casing, which during the shut-down compensates the heat loss due to convection inside the turbine. Electrical resistance heating, as shown diagrammatically in Figure 6, in particular enables, as shown by experience, the heating load to be readily adjusted, so that the casing will not become bent. All these measures react also favorably on the stationary rotor, because the temperature compensation achieved with the heating arrangement improves also the conditions for the shaft. The same effect may be obtained by artificial cooling of the upper part of the casing, as in this manner the heat rising to the top is more rapidly conducted away. Such a process would be useful in order to bring the turbine as rapidly as possible out of the half-warm state. It may, however, have undesirable effects, because considerable temperature differences between the walls of the casing and the thick flange parts may occur, tending to cause distortion.

In the case of large turbines so-called turning gears have long been in use, by means of which, during a shut-down, the shaft is slowly rotated by hand or by a motor. G. B. Warren[2] for instance reports on the high sensitivity of a half-warm machine when restarting, and on the great improvement in the starting conditions brought about by rotation of the shaft after shutting down (Figure 7). This rotation is effected nowadays even with

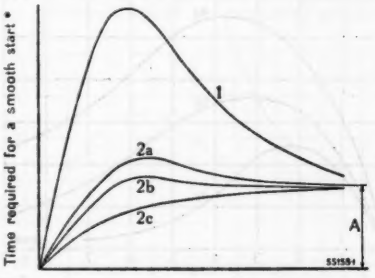


Fig. 7. — Time required for smooth running up as a function of the time of shut-down. The shaft distortion which at first increases and then slowly decreases, makes a careful and slow restarting necessary. The conditions may be considerably improved by rotation of the shaft during the shut-down (see General Electric Review, Nov., 1940).

1. Starting time without shaft rotation.
2a—2c. Starting time with shaft rotation.
A. Usual starting time for a cold machine approximately 1 hour.

* Depends on size of machine, temperature and load before shutting down.

[2] G. B. Warren "Progress in Design and Performance of Modern Large Steam Turbines for Generator Drive". General Electric Review Nov., 1940, page 450, Figure 34.

motor-drive with a speed of only about 1 Rpm. This slow peripheral speed naturally makes proper lubrication difficult, and turning devices are accordingly often provided with an additional high-pressure oil pump, in order to lift the shaft from the bearing by means of an oil film. Finally, the device requires interlocking features, in order to prevent the turning gear from being engaged when the turbine is in operation, or conversely, to prevent the turbine from being started up as long as the turning device is engaged. The continuous rotation of the shaft during the shut-down is frequently replaced by periodic rotation through half a revolution, thus making high-pressure lubrication superfluous.

II. Shutting Down and Preparing a Turbine for Restarting.

In considering the factors having an effect on restarting, it is first of all necessary to distinguish between the following three cases:

1. Shutting down for a long interval.
2. Shutting down for restarting at a given moment.
3. Shutting down for restarting at any instant.

1. *Shutting down for a long interval* requires no special measures. The distortion caused by the heat flow inside the turbine attains its maximum in a few hours, and then decreases as the turbine cools down, at first rapidly and then more and more slowly. Figure 8[3] shows the way in which the distortion of a turbine shaft varies after shutting down. This distortion depends, of course, both on the design of the turbine and the temperature, that is, on the load at the moment of shutting down. As is to be expected, the distortion occurring after a reduced load run decreases in accordance with

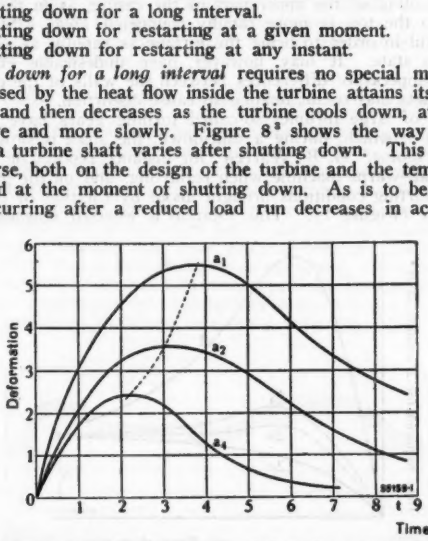


Fig. 8. — Upward deformation of the shaft during a shut-down. The three curves show the important effect of the load, that is to say of the temperature along the turbine before its shut-down. The deformation can be considerably reduced by decreasing the load or by allowing the set to run light.

Variation of the deformation with:

Deformation: a_1. Full load.
a_2. Full load + 20 min. light run.
a_4. Light running only.

[3] In Figures 8, 9, and 10 no scale is given either for the time or deformation ordinates, as both vary from case to case, depending upon the type and size of machine. To give an idea of magnitude, however, the figures may be taken to represent hours and tenths of millimetres, respectively.

the reduced temperature, and the restoration of the shaft shape also takes place in a shorter time. This effect of the load on the machine before shutting down is of particular importance for the cases 2 and 3.

2. *Shutting down for restarting at a given moment does* not require any special precautions, because, since the moment of restarting is known, all the manipulations necessary for a smooth running up may be effected shortly in advance of restarting. If the shut-down period is sufficiently long, for instance from the evening to the following morning, the straightening-out process, especially if the load has been reduced before stopping or if the machine has been allowed to run light for some time, may have gone so far as to make any special measures for restarting unnecessary.

It should be remarked here that it is still possible to start up again with a small deformation of the shaft, because vibrations do not take place at the reduced speed maintained during warming up. Contact of the steam with the rotating shaft soon causes the latter to straighten out, and the machine can then be run up in the usual manner and paralleled. Even if slight vibrations occur, these disappear after a while upon temporarily reducing the speed, due to the shaft straightening out. Thereupon the speed can be increased again. It should always be bore in mind that the deformations of the shaft and of the casing must definitely lie within the clearance margin, in order that no rubbing shall take place during the first few revolutions, because an increase in the gland clearance would result in a reduction of the efficiency of the machine. If the shut-down is so short, as to necessitate a reduction of the deformation still persisting, it is generally sufficient to give the shaft half a turn shortly before restarting, in order that it may become straight by the time it is due to go into service again. By giving the shaft half a turn, the hotter half is transferred to the bottom, and the heat flow immediately set up cools the hotter parts and warms the colder upper ones. Figure 9 shows the conditions graphically. The ampli-

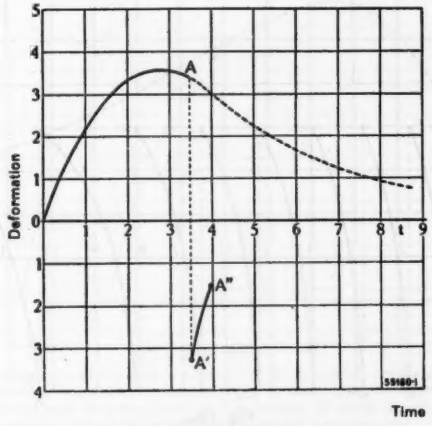


Fig. 9. — Representation of the shaft deformation upon rotation of the shaft through half a revolution approximately half an hour before restarting. The natural deformation is caused to retrogress quickly by means of a half revolution and enables the turbine to be run up practically without vibration.

tude of the curve depends upon the load before shutting down. For a given curve, the deformation (point A) will be greater or smaller according to the instant considered, and hence the shaft will, after rotation through half a revolution, approximate more or less closely to the straight condition (point A"). The smallness of the difference is then generally sufficient guarantee of a safe starting of the turbine. Naturally the time required between the half revolution and restarting of the turbine depends upon the duration of the shut-down. This time can, however, be quickly and definitely determined from the early operating experience with the turbo-set. This simple measure then provides the necessary condition for satisfactory restarting.

3. *Restarting at any instant* differs from the two above cases in that the shaft has to be kept constantly straight within the allowable tolerance, in order that there shall never be any possibility of the rotor rubbing against the casing. Upon restarting, there occur then, at the most, slight vibrations until the shaft has straightened itself out, through slow rotation in contact with the steam. Continuous turning of the shaft by means of a motor drive has already been mentioned as a suitable solution maintaining the shaft straight.

Figure 10a shows how the natural deformation a_1 of the shaft (Figure 8) can also be kept within the admissible tolerances v and —v, by means of periodical rotation through half a revolution, thus again avoiding any possibility of rubbing of the shaft on the casing.

After such a half-revolution the shaft is distorted downwards by the same amount that it was previously distorted upwards, and the heat flow causes the deformation to retrogress until it crosses the axis and begins to build upwards. After a certain time the limit is again reached, so that the shaft has to be rotated once more. Because of the general cooling effect

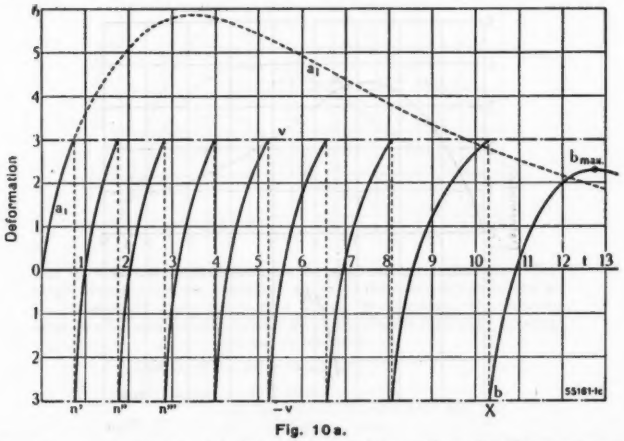


Fig. 10a.

10a. By means of rotation of the shaft through one half revolution the deformation may be kept within the admissible tolerances v and -v. The general cooling effect causes the time interval between successive half turns n', n'', n''' to become steadily larger.
X Last rotation.

FIGURE 10.—BEHAVIOR OF A SHAFT DEFORMATION WITH PERIODICAL ROTATION OF THE SHAFT THROUGH ONE-HALF REVOLUTION DURING SHUT-DOWN.

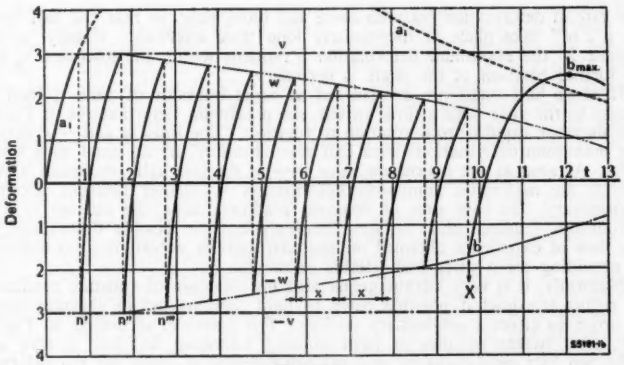


Fig. 10b.

10b. With periodic rotation of the shaft through one half revolution at equal time intervals x, the maximum deformations (w and -w) become smaller and smaller.
X Last rotation.

FIGURE 10.—BEHAVIOR OF A SHAFT DEFORMATION WITH PERIODICAL ROTATION OF THE SHAFT THROUGH ONE-HALF REVOLUTION DURING SHUT-DOWN.

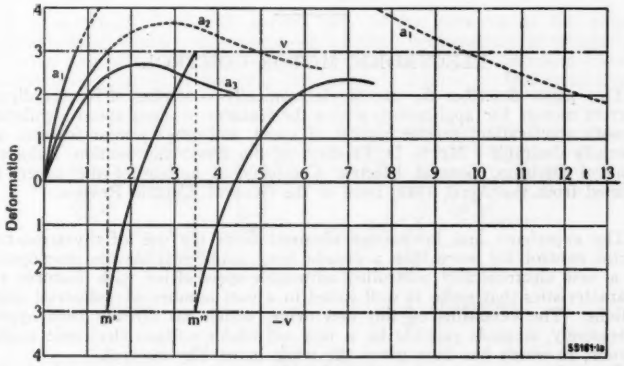


Fig. 10c.

10c. By removing the load from the turbine before shutting down, the number of rotations through half a revolution m', m'', in order to keep within the tolerances, is considerably reduced or it may even be unnecessary to rotate the shaft at all.
a_1 Deformation with the turbine left to itself.
a_2 Behaviour of the maximum deformation after light running before shutting down.
a_3 Deformation after a prolonged light running falling inside the tolerance limit v.

FIGURE 10.—BEHAVIOR OF A SHAFT DEFORMATION WITH PERIODICAL ROTATION OF THE SHAFT THROUGH ONE-HALF REVOLUTION DURING SHUT-DOWN.

the rate of deformation becomes more and more slow, so that the half turns n′, n″, n‴ take place at increasingly long time intervals. Finally, at the instant X, the maximum deformation b remains within the tolerance v, and no further rotation of the shaft is necessary.

If these half turns are carried out at equal intervals of time t, such as would be the case with a time switch, the maximum deformations of Figure 10b decrease rapidly from rotation to rotation. The lines w and —w denote the maximum deformations with half revolutions n′, n″ at equal time intervals. As soon as the maximum value b^{max} of the last half revolution b falls within the maximum admissible deformation v, further rotation becomes unnecessary. In this case of constant readiness also, the number of half revolutions required and the time intervals may be readily determined on the base of experience obtained on site, and there is accordingly no difficulty in providing for a quick and reliable restarting.

Naturally, it is very advantageous also for this case of constant readiness, to reduce the load if possible down to light running before shutting down, in order to effect a preliminary cooling. For instance, according to Figure 10c, after twenty minutes of light running following full load (curve a_2), only two half revolutions m′ and m″ are required in order for the deformation to remain within the tolerances +v and —v. Further, it can readily be conceived that a still longer period of light running before shutting down would so reduce the subsequent deformations a_2, as to make it unnecessary to turn the shaft even only once or twice. Generally, however, the time of light running required to achieve this result would be much too long, so that the few turns needed with a reduced period of light running are to be preferred.

ELECTRONIC MOTOR CONTROL.

This paper describes the use of electronically controlled drive for direct-current motors for applications where the features of close speed regulation, smooth acceleration, precise control of speed, and other similar features are specially desirable. Mr. S. D. Fendley, of the Electronic Section, Industrial Control Division, General Electric Company, is author of the paper, reprinted from the April, 1943, issue of the General Electric Review.

The experience and knowledge obtained from the use of thyratron-tube motor control for more than a decade have made possible the development of a new electronically controlled adjustable-speed drive with features and characteristics that make it well suited to a vast number of industrial applications. The versatility of this new drive, which has already been applied extensively, is made possible by a new adjustable-voltage electronic control system, to which has been given the trade name Thy-mo-trol.

To preface the description of how this new control operates and of what it consists, it might be well to review briefly the operation and application of earlier types of electronic motor controls.

One of the earliest applications of electronic motor control was to the operation of an automatic lighting control installed about 1928. In this application, thyratron tubes were used to supply both the field and armature of a small motor to control its speed over a range of approximately 100 Rpm. to 3600 Rpm. Following this many thyratron speed-control equipments were furnished for motors of various sizes and for many different applications.

The primary function of practically all of the original motor controls has been to adjust the speed of the motor. The other requirements such as starting, accelerating, etc., have been obtained largely through the use of various combinations of conventional control devices. A few equipments have been supplied for holding the motor speed constant, but in general their principal function has been to supply smooth, adjustable speed.

There are in service a relatively large number of thyratron motor-speed controls and there are many applications in industry for the use of such equipment.

Generally speaking, these equipments consist of an adjustable-voltage rectifier using thyratron tubes to supply the d-c for the field and armature of the motor. By varying the output voltage of the tubes the speed of the motor can be changed. Some type of feed-back system is employed to do this, and it may be of either the mechanical or electrical type.

The phase-shift method is one of the most common ways of adjusting the output voltage of a thyratron tube. This employs the use of a resistance-reactance bridge which permits the phase relation of the grid voltage to be varied with respect to the anode voltage. By varying one of the elements in the bridge circuit, it is possible to change the phase displacement of the grid voltage with respect to the anode voltage from a condition where the two are completely in phase to the point where they are 180 degrees out of phase. When the two voltages are completely in phase, the tube will be turned full-on. When they are completely out of phase, the tube will be turned off completely and will not conduct any current. By adjusting the voltage relation between these limits, the tubes can be turned on to any desired degree.

Mechanical Feed-back Arrangement.

In a mechanical feed-back system, one of the elements in the phase-shifting bridge—usually the reactor—is adjusted mechanically to change the output of the tubes and thus regulate the speed of the controlled motor. Several arrangements of this type are shown in Figure 1. In one of these,

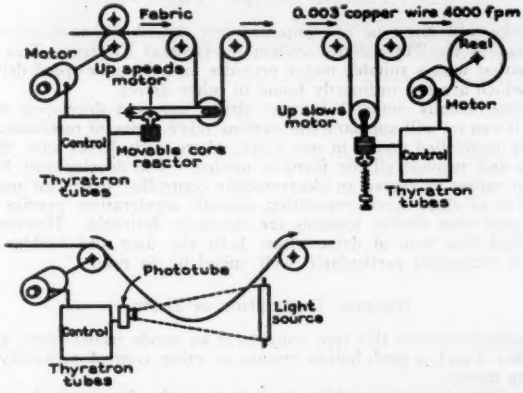


Fig. 1. Sketches illustrating various mechanical feed-back arrangements as employed with earlier electronic motor controls.

a loop of material being processed—this may be fabric, rubber sheeting, sheet steel, etc.—is used to operate the movable core of the reactor which thus adjusts the speed of the motor in proportion to the rise and fall of the loop.

In some instances, where it is not practical to use a mechanical arrangement employing the reactor, the motor speed can be controlled through the use of a photoelectric arrangement as shown in the lower sketch in Figure 1. A light beam is directed on the loop of material, and as the loop rises and falls it varies the amount of light falling on the phototube. This causes the motor speed to be increased or decreased through the use of the thyratron tubes in the same manner as with the reactor scheme.

The basic circuit for all equipments of this type employs two thyratron tubes to supply direct current to the motor field. The field voltage is adjusted by changing the position of the core in the reactor. Within the rating of available tubes, similar equipment can be used to control armature voltage.

Typical of the applications employing this type of control is the maintaining of constant tension in the reeling of wire, ranging from fine copper wire to large, heavy cable. Another similar application is that of synchronizing the speed of conveyors with that of a material in a plastic state as it emerges from an extruding machine, and for maintaining a fixed relationship between two or more conveyors which must handle the same material. Numerous applications of this type may be found in the rubber industry.

Electrical Feed-back Arrangement.

Where speed regulation is an essential factor, the electrical feed-back arrangement, utilizing a pilot generator with a suitable circuit, makes it possible to hold the speed of a motor very nearly constant over a wide range of loads.

As in the mechanical arrangement, a full-wave rectifier is used, but a saturable reactor instead of a movable core reactor adjusts the voltage applied to the motor.

Fully Automatic Control (Thy-mo-trol).

Experience with the type of equipment just described has resulted in the development of the Thy-mo-trol system by General Electric. This control in combination with a suitable motor provides an adjustable-speed drive with features which are not ordinarily found in other drives.

This electronically controlled motor drive was not developed with the idea that it can or will supplant the various other types of mechanically and electrically controlled drives in use today, where such drives have the characteristics and provide all the features needed. The development has been carried on rather to evolve an electronically controlled drive for use where the features of close speed regulation, smooth acceleration, precise control of speed, and other similar features are especially desirable. However, it is believed that this type of drive offers both the user and builder of machinery an equipment particularly well suited to his needs.

General Description of Drive.

The standard drive of this type consists of an anode transformer, a control and rectifier panel, a push-button station or other control accessory, and a d-c driving motor.

In some instances, a smoothing reactor may also be required, depending upon the size and characteristics of the motor being used.

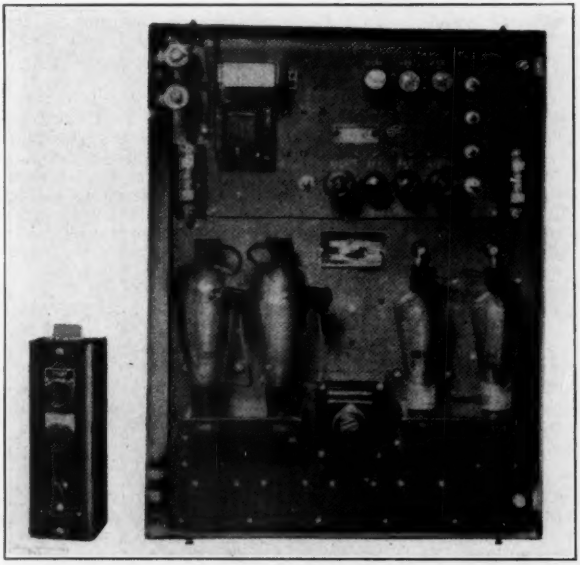


FIGURE 2.—THY-MO-TROL PANEL (RIGHT) AND HEAVY-DUTY-TYPE PUSH-BUTTON STATION—THESE TOGETHER WITH AN ANODE TRANSFORMER AND A D-C DRIVING MOTOR COMPRISE THE STANDARD THY-MO-TROL DRIVE.

Anode Transformer.—The anode transformer is used in order to make use of motors of standard voltage. By designing a special motor, it would be possible to eliminate this transformer entirely in most cases, but it is felt that the use of a motor of standard design has definite advantages to the user.

The transformer is of conventional design and may be either of the insulating or of the autotransformer type. It is generally installed as a separate item to keep to a minimum the size, weight, and cost of the rectifier cabinet in which it might otherwise be located.

Control and Rectifier Panel.—In Figure 2 (right) is shown a conventional type of control panel. It consists of a suitable base on which are assembled the control and power tubes, a line contactor, a thermal overload relay, a field-failure relay, a cathode-protective timer and the necessary transformers, and other material required for the electronic circuit. Suitable anode fuses are provided for protection against short circuits.

The panel is hinged in the stationary part of the enclosing cabinet and by loosening suitable screws it can be swung completely open so that the parts and wiring are readily accessible.

The control tubes and other parts associated with them are mounted on an individual sub-panel which can be removed quickly and replaced by another unit with little loss of time.

Accessory Control.—The control accessory, shown at the left in Figure 2, is a standard heavy-duty-type push-button station in which are mounted the necessary number of momentary contact units and the speed-adjusting potentiometer. Both the speed-adjusting potentiometer and the momentary control units may be installed as separate items that can be mounted in any convenient location.

Motor.—A shunt-wound d-c motor is used. In order to make more economical use of the rectifier tubes, 230-volt machines are ordinarily installed.

Although the motor is of conventional design, its characteristics must be such that it will operate satisfactorily from an unfiltered rectifier supply. This is particularly true when the a-c power supply is single phase.

Electrical Characteristics.

Acceleration.—One of the characteristics of a good drive is that it should be capable of starting its load with a minimum of shock to the machine and under conditions which will permit the motor to commutate satisfactorily. From an engineering point of view, the accelerating scheme employed in this drive is one which does approach this ideal. It is termed constant-current limit acceleration. By means of an adjustment in the panel, it is possible to vary the accelerating current and thus the accelerating torque to a value which will bring the motor up to operating speed in the quickest time consistent with the nature of the load and the commutating ability of the motor.

From the moment the start button is pressed, the motor will draw the maximum value of current determined by the adjustment. Under these conditions the motor will pull with smooth, uniform torque until the load is up to speed; then the current will drop off to the value needed to maintain the required torque.

Preset Control.—For many applications, it is desirable to preset the speed at which the motor is to operate anywhere within the operating range. This type of equipment provides this feature so that the motor will be accelerated smoothly up to the speed called for by the setting of the potentiometer. The motor is always started under full-field conditions regardless of whether the potentiometer is set for operation below base speed by armature-voltage control or above base speed in the field-weakening range.

Overload Protection.—Protection against sustained overload is provided by means of a conventional thermal overload relay.

Stopping.—Quick stopping of the motor is provided by means of conventional dynamic braking. When the stop button is pressed, the power is disconnected and a resistor is connected across the armature.

Regeneration or Pump-back.—The standard equipment does not provide for regeneration or pump-back, so that when the speed-adjusting potentiometer is quickly turned from a high setting to a lower one, the motor will coast down to the new setting at a rate which will be determined largely by the amount of the load. This means that it is not suitable for use with overhauling loads.

Another factor is that when motor speed is being reduced with field applied, the motor acts as a generator and tends to generate an excessively high voltage. In the Thy-mo-trol system, a "voltage-snubbing" circuit automatically keeps the voltage down to a safe value.

Where quick slow-down is required, a modification can be employed which provides a form of automatic dynamic braking to slow down the motor. Except in special instances, this feature has not been found essential. A typical application where it may be necessary is in the case of a turret lathe where the operating speeds must be stepped up or down rapidly so as to be proper for whichever turret tool is being used and to maintain maximum production.

Speed-range.—The speed-range obtainable with equipment of this type is largely a function of the size and type of motor employed. The range, theoretically, is from a value approaching zero up to the maximum for which the motor is designed to operate by field weakening. The practical limits are largely determined by the heating and stability of the motor. From tests which have been made it appears that the motors can be operated over a range of up to 20-to-1 below base speed by armature control on an intermittent basis without exceeding a dangerous temperature rise, and as high by field control as the motor is designed to operate. Much, however, depends upon the nature of the load to be handled, the duty cycle, etc.

Regulation.—By providing closely regulated armature voltage and automatic compensation for RI drop, this system holds the motor speed constant within close limits, independent of load and ordinary line-voltage variations. An adjustment in the panel makes it possible to adjust the regulation to provide a drooping speed characteristic where this is desirable.

For a given speed setting, the equipment can be adjusted to hold the regulation to a value of approximately 2 per cent variation from no load to full load when operating below the basic motor speed. When the motor is operating in the field weakening range, the speed will decrease with load, to a value not exceeding 10 per cent depending upon the rating of the drive.

The close regulation provided by the system makes it possible to operate the motor on a constant-torque basis below base speed at any speed within the stable operating range. This means that it is possible to get a motor to operate at some low speed, such as 100 Rpm., for example, and maintain this within close limits even though the load may vary from no load to full load.

For applications where a more precise speed regulation is desired than that obtained with the standard equipments, it is possible to use the output voltage of a tachometer generator in the circuit and obtain a speed regulation on the order of plus or minus ½ per cent from no load to full load. This arrangement provides exceptionally close regulation regardless of line-voltage variation. Certain types of testing equipment often demand regulation of this low magnitude.

Effects of a-c Voltage Variation.—The system will operate successfully on line-voltage variations of as much as 10 per cent of rated voltage, but to obtain maximum tube life the variation should not exceed plus or minus 5 per cent.

For a plus or minus 5 per cent line-voltage variation, tests have indicated that when operating over a range from 5 per cent of base speed up to 2-to-1 by field control, the speed will not vary more than plus or minus 1 per cent.

Tube Failure.—One very important consideration with any electronic equipment is the question of what will happen if one or more of the tubes should fail. In this system, the circuits have been so designed that the equipment is entirely safe regardless of which tube or combination of tubes may fail. The equipment will either shut down instantly or will continue to operate, deprived of the function of the tube which fails.

Protection Against Damage From Transient Voltages.—All of the inductive circuits in the system which might be injured due to excessive voltage are protected by Thyrite units which keep the voltage rise within safe limits.

Principle of Operation.

The operation of the equipment can best be understood by considering individually the part which makes up the power circuit and that which constitutes the control circuit.

From the diagram shown in Figure 3 it can be seen that a pair of tubes (*Tube 1* and *Tube 2*) constitutes a full-wave rectifier which converts to direct current the alternating current supplied by the anode transformer. The direct current is then fed through the armature of the motor. Likewise,

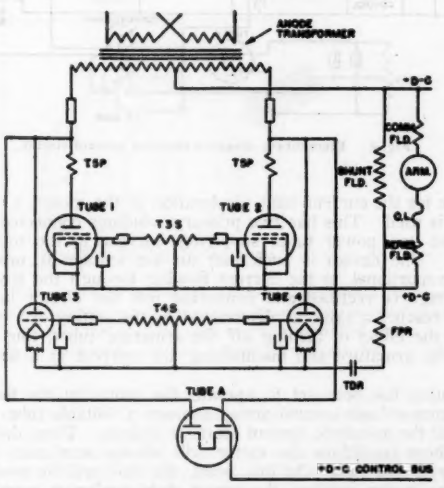


Fig. 3. Circuit diagram showing thyratron rectifiers connected to motor.

Tube 3 and *Tube 4* make up a full-wave rectifier, which supplies direct current to the shunt field of the motor. By adjusting the outputs of these two rectifiers, it is possible to control the operation of the motor. Its speed can be adjusted from zero, by armature-voltage control, up to maximum for which the particular motor is designed to operate by field weakening.

Electronic Control Circuits.—The output of the power rectifiers is adjusted by a group of radio-type control tubes, whose basic circuit is shown in Figure 4. Acting as amplifiers of current and voltage signals received from the motor circuit, these tubes supply the necessary direct current to the saturating winding of the saturable-core reactor in the resistance-reactance bridge which is used to adjust the output voltage of the power rectifiers by the phase-shift method previously described. By adjusting the current in the saturating winding, the power tubes are turned on or off as required to give the desired motor performance.

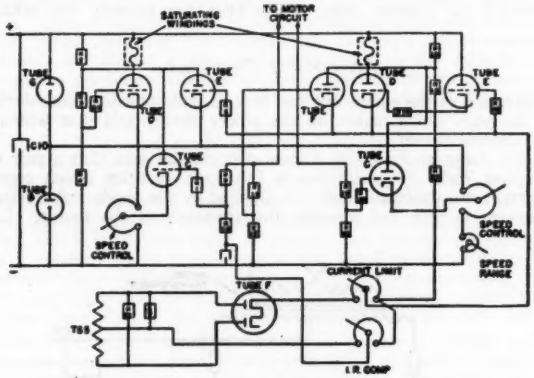


Fig. 4. Elementary diagram showing control circuit.

To provide for the current-limit acceleration of the motor, a current transformer, T_5, is used. This has two primary windings connected in the anode circuit of the two power tubes supplying current to the motor armature (Figure 3). The design is such that an a-c voltage is produced in the secondary, proportional to the current flowing through the thyratron tubes. The a-c voltage is rectified and connected into the circuit in such a way that when it reaches a value as determined by the setting of a potentiometer, it will have the effect of turning off the armature tubes, thus reducing the voltage on the armature and maintaining the current at a fixed maximum value.

If the control has been set to operate the motor in the field-weakening range, the current-limit control acting through a suitable tube will maintain full field until the armature current starts to reduce. Thus, during acceleration under these conditions the motor will always accelerate from zero to base speed with full field. At this point, the field will be weakened gradually until the motor reaches the preset field-weakened speed. Then the armature current will drop to the value necessary to drive the load.

The adjustment of the speed is controlled by two adjustable potentiometers—one controls armature voltage, the other controls field voltage. The potentiometers are operated from a single shaft and are so arranged that approximately half of the rotation of the adjusting knob will vary the armature voltage from approximately zero to maximum. Then the other potentiometer becomes effective, and further turning will tend to reduce the field voltage so that the motor speed can be increased to the value desired, up to the maximum for which the particular motor is designed to operate by field weakening.

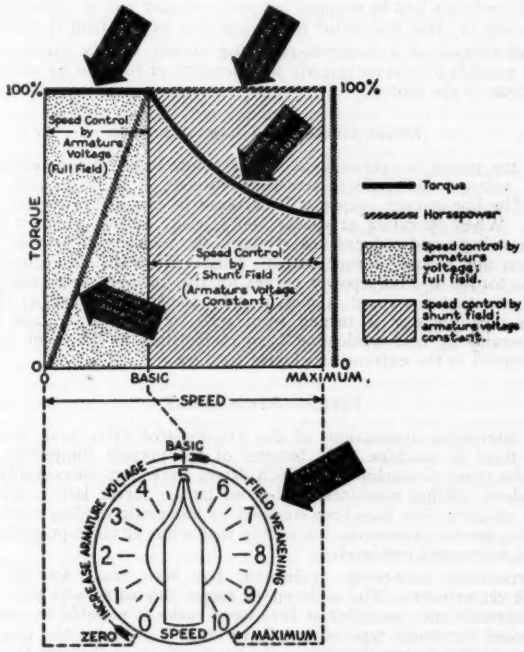


Fig. 5. Curve showing that motor torque and horsepower characteristics vary with motor speed. Coupled with curve is drawing of speed control dial showing that speed is controlled in the armature and field ranges by a single dial.

To maintain accurately the preset speed, it is necessary to hold armature counter-emf constant. This can be done by increasing the armature terminal voltage by an amount equal to the IR drop of the armature circuit. In this system, this is accomplished through the use of the same current transformer that controls the current limit. The circuit functions in such a manner that as armature current increases, the thyratrons in the armature circuit are turned on, thus increasing the armature voltage. If the load

increases, the circuit operates to increase the armature voltage proportionally, which thus acts to maintain the speed at its preset level. An adjustable potentiometer used in the circuit makes it possible to maintain essentially constant speed from no load to full load for any given speed setting, or to provide a drooping speed characteristic where desirable.

When the start button is pressed, the motor will be accelerated rapidly and smoothly by current limit, as described, until it reaches a speed corresponding to the setting of the speed-adjusting potentiometer. The motor will then maintain this speed closely, irrespective of variations in load, within the limits of the IR-drop-compensation feature. When the stop button is pressed, the anode contactor will be dropped out and a resistor will be connected across the armature to bring the motor to a quick stop as full field is applied.

The substitution of a magnetic-reversing switch for the anode contactor makes it possible to reverse quickly the direction of rotation by current-limit regeneration of the motor.

Motor Operating Characteristics.

When the motor is operating at speeds below basic, during which it has full-field voltage and reduced-armature voltage, it will provide constant torque. The horsepower output will decrease in proportion to the decrease in speed. When operating at speeds above basic, during which it has full-armature voltage and reduced-field voltage, the motor will provide constant horsepower and reduced torque output. This is illustrated in Figure 5 which shows the torque and horsepower curves for the full operating range. Figure 5 also shows that the speed is increased by armature voltage as the speed adjusting potentiometer is turned from zero to midposition, and that the motor operates by field weakening from midposition to the point where the knob is turned to the extreme clockwise position.

Typical Applications.

Many interesting applications of the Thy-mo-trol drive have been made, most of them to machine tools because of the present limitations in size. Among the types of machines to which drives have been successfully applied are grinders, milling machines, tool-room lathes, turret lathes, and thread mills. In addition, they have been supplied for automatic welding machines and for various special equipments for testing magnetos, airplane-propeller governors, and instrument tachometers.

A particularly interesting application has been made for driving the headstock on grinders. The wide speed range obtainable and the constant-torque characteristics provided at low speed make it possible to provide the proper speed for every type of grind. In several instances the new control has made possible a simplification in the headstock itself through the elimination of gears and pulleys formerly required.

Another important factor in this application is that the equipment can be mounted on the grinder without fear of introducing any undesirable vibration such as might be produced with high-speed rotating apparatus. The machine can be made entirely self-contained, and it can be moved at will without worry as to the availability of a d-c power supply.

For reversing table drives, the use of two independent speed-adjusting potentiometers makes it possible to provide full-range, independently adjustable speed for both directions of travel. A simple relay for selection between the potentiometers and a standard double-throw limit switch are all the additional material needed.

THE EXTREME PROPERTIES OF MATTER.

This is an abridged copy of the 49th James Forrest Lecture, delivered by Sir Charles Darwin, K.B.E., F.R.S., at a meeting of the Institution of Civil Engineers, held in London on January 12, 1943. His lecture was published in three issues of Engineering (London) on February 5, 12 and 19, 1943.

It is not easy to choose a short title which conveys clearly the subject that I propose to discuss, so I had better begin by explaining what this rather cryptic name means. I remember, during the last war, reading a "spy" story which from beginning to end had little merit, but contained one gem of purest ray serene. This was a conspiracy to steal a priceless military secret, the plan for making a gas with three times the lifting power of hydrogen! I dare say many unsophisticated readers swallowed this as no worse than any of the author's other flights of imagination, but, since hydrogen already gives 93 per cent of the lift that could be obtained from a vacuum, it was rather hard to feel that the spy was really earning his pay when he got away with the plan. The point of this rather trivial example is that physical science can now assign with confidence many limitations on the properties of matter, so that, just as we could always say with certainty that we could not possibly get a gas to lift a balloon that would be more than 7 per cent better than hydrogen, so we now know a great many other absolute limitations to which matter is subject. I have thought that it would be in consonance with the general purpose of the James Forrest Lectures if I took a number of the more practically interesting properties of matter, and attempted to describe what the extreme values might be, beyond which we could never hope to go. I can, of course, only discuss a few, and my selection includes the mechanical properties of solids, liquids, and gases, and some of their electric and magnetic properties.

It may appear to be a foolhardy ambition to presume to lay down such limitations, and you may be feeling that my prediction could be easily upset by the discovery of some new substance. It would have been presumptuous to do so 40 years ago, but with the discovery of atomic number, about 1912, we can now say that there is no room for any new kinds of matter. To each chemical element can be assigned a number, for example, hydrogen 1, iron 26, etc., representing the number of electrons necessary in order exactly to neutralize the intense positive charge of the nucleus of its atoms. Every substance known fits exactly into this list, which ranges from 1 to 92 (hydrogen to uranium), and the converse is nearly true in that, corresponding to every number, there is a known element. Even at first there were only a few gaps, and by the help of the principle of atomic number these have mostly since been filled; for example, at first 72 was vacant, but Bohr predicted that it ought to be chemically rather like 40, which is zirconium, and a search soon discovered the new element, hafnium. There are still one or two gaps, but we can confidently say that if the elements exist they are very rare, and so of little practical importance, and furthermore, that their general properties can be foreseen from chemical theory with considerable confidence. Beyond uranium there are two more, which have been observed in minute quantities at 93 and 94, and that completes the list. In addition to these elements, there are a few other particles of a different kind, chief among which is the electron, which, I may remind you, is a very light and all-pervading negatively charged particle. In addition, there are certain rather newly discovered particles, the neutron, the positron, and others, which are intensely interesting, but which will not concern us, since, loosely speaking, they come into evidence only temporarily and refuse to "stay put." That is the whole list. We may

confidently say that, apart, perhaps, from these transient particles, we have all the cards of the pack, and that no one will produce a joker from his sleeve. The only new discoveries that can be made will be made, not by producing new cards, but only by forming new combinations of the known ones.

The Characteristics of the Solid State.—My first subject will be the one most interesting to engineers, the characteristics of the solid state. Unfortunately, it is the most difficult subject of all, and there is no doctrine about it really accepted by everyone, so that what I shall say is partly controversial. Still more unfortunately, it is not a subject in which I have any right to speak with authority, and the activities of recent times have left me little opportunity for following the work closely. Therefore you must not take my remarks to be guaranteed against error, but I have thought that it would be more interesting to give speculative views than to show such caution that, while everything would have been certainly true, it would equally certainly have been extremely dull.

We know a good deal by now about the forces which act between atoms. There are several rather different types of force which occur in various types of solids, and the type which concerns us here is the metallic one, since, in considering the strength of materials we obviously turn first to the metals. The basic structure of a metal is a crystal, usually of one of the simplest and most symmetrical classes. In this crystal the atoms have each set free one or more electrons, and these wander about freely as a sort of cloud. This cloud of negative electricity acts as a sort of cement holding together the positively charged atoms. In addition, these atoms exert forces on one another, partly of the repulsive electric type that would be expected, but also others of a kind, the principle of which is to be mastered only by going rather deeply into quantum theory. The behavior of these forces can be imitated by thinking of atoms as exerting attractions or repulsions on one another, but these forces need no longer conform rigorously to the pure electric type. The only character of them that I need at the moment is that they are not to vary violently with the distance; that is to say, if, in equilibrium, one of the forces between two adjacent atoms is so and so, then, if they are displaced to a distance not greater, say, than 20 per cent, this force will not have altered by more than, say, a factor of 2.

Let us now examine what we should expect for the strength of a crystal based on this model. Consider, as the most characteristic thing in a solid, its shearing strength. Figure 1 shows two rows of atoms, each of which is intended to represent a whole sheet of atoms standing out at right angles to the paper. The sheets are held together by their mutual atomic forces, together with those coming from the atoms in the sheets above A and below B, which are not shown. In the unstressed condition, the atoms of A and B are supposed to be exactly opposite one another, but this is unessential to the argument; the first atom of A would therefore be at the point L. Now impose a small shear by displacing the whole sheet A, and all above it, a little to the right. A force will at once come into play resisting this displacement, and we can tell what this force is by our knowledge of the shear modulus. We can conveniently represent what happens by making a diagram, Figure 2, in which the stress is plotted against the displacement of the sheet of atoms A, and the shear modulus gives the direction of the tangent at L. As to what happens farther on, we cannot be sure, but we do know that, if the A sheet is bodily transplanted one atom's length along to M, the force will vanish again, and round this point the curve will repeat itself. Moreover, halfway between there must be another point of equilibrium, and this must be unstable, because it lies between two points of stable equilibrium. This will be represented by the point N and a tangent sloping the other way. We do not know how to complete this curve, but we can make very useful conjectures about it. From all reasonable assumptions about the atomic forces being continuously variable with the distance between the atoms, we may say that

Fig.1.

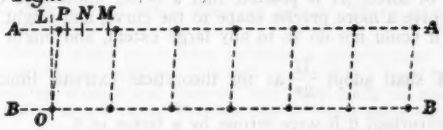


Fig.2.

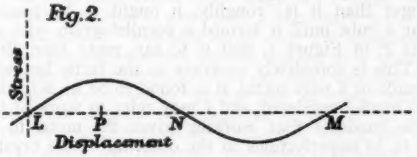
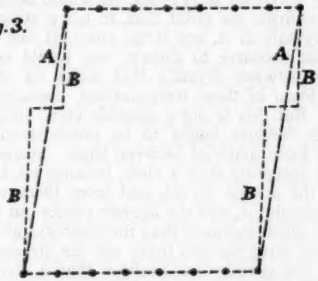


Fig.3.



the curve should have a reasonably smooth form. The simplest one to take is a sine curve, so we will adopt that. We know the slope at L, and the position of N, and from these it is elementary to calculate the height to which the curve rises at the point P, one-quarter way along from O to M. This will give the maximum stress that the metal can stand without yielding. An elementary calculation shows that this stress is $\frac{G}{2\pi}$, where G denotes the shear modulus. For a good steel, the value of G is about 6000 tons per square inch, and this suggests a shear strength of about 1000 tons per square inch, in contrast to 10 tons per square inch, which is roughly the actual value.

Thus the answer is something like one hundred times greater than the value actually found, and we have to examine it critically. As it has been an entirely arbitrary assumption that the curve is a sine curve, we will change this to see if we can get a lower value in any reasonable manner. Obviously, it is possible to round the curve off quite perceptibly, but a little consideration shows that nothing can be done to cut it down one hundred-fold, since this would mean that a very slight displacement of the sheet A would have to cause the atomic forces to drop violently to zero. This is not a reasonable assumption in any way, if only because those forces are a balance of attractions and repulsions, and to get a sudden upset of the almost discontinuous kind that is demanded between these forces would call for exceedingly un-

natural laws of force. It is possible that a better knowledge of the atomic forces might give a more precise shape to the curve, and might lower its top slightly, but it could not do so to any large extent, and might even raise it instead; so I shall adopt $\frac{G}{2\pi}$ as the theoretical extreme limit, and should certainly be surprised if it were wrong by a factor of 2.

The argument I have given suggests that a crystal of a metal ought to be very much stronger than it is; roughly, it ought to be possible, without breaking, to shear a cube until it formed a parallelogram with angles given by the slope of O P in Figure 1, that is to say, more than 10 degrees off the right angle. This is completely contrary to the facts, for, when a single large crystal is made of a pure metal, it is found to be as soft as putty. This difficulty has been much considered, and I may refer to work of G. I. Taylor, who attributed the hardness that working gives the metal to "centers of dislocation," that is, to imperfections in the ordering of the crystal, an effect which is practically universal in crystals. It would be out of place to go into his theory, but it confirms the point that, to get a strong piece of metal, one must have small crystals in it, not large ones. If one examined the experimental facts without recourse to theory, one would conclude that it is the irregular junctions between crystals that make its strength, and that the metal is a sort of foam of these irregularities, containing in its bubbles the putty-like crystals. But this is not a possible view, since we have to face the difficulty that those bubbles ought to be much stronger, by our previous argument, than the foam material between them. Moreover, there is an even greater difficulty in accepting such a view, because we know, at least roughly, the magnitudes of the atomic forces, and from them we can calculate what the shear modulus should be, and the answer comes out about right. Thus the crystals ought to be much stronger than the intercrystalline irregularities; and yet the more of these irregularities there are the stronger the metal becomes. We seem to be in the paradoxical position that a chain is strengthened by multiplying the number of its weakest links!

Some recent ideas of Bragg and others have done much to clear up the situation. In the model I took of the sheared crystal, I imagined the atoms on each sheet rigidly held together in relatively fixed positions. In fact, however, they are not fixed, since temperature dictates that atoms can never be at rest. Each atom is oscillating all the time in an irregular manner about its average position, and this makes possible a readjustment among the atoms, without calling into play the strong stresses which would arise if the whole sheet had to be displaced like a rigid body. Consider the matter in more detail. A piece of metal is now to be regarded as composed of a large number of small crystals, all differently oriented and held together by a cement of irregularly placed atoms. When one of the blocks of crystal, several layers thick, is sheared a little, the displacements of the atoms (more strictly, now, of the average positions of the atoms) will call into play reactive forces which provide the shearing stress. But if the shear is made larger a new possibility occurs, which is that a slip should occur between the two rows. On account of the heat motions of the atoms, this may now occur without calling into play the violent reactions that our previous argument suggested; and, to decide whether it will occur or not, we adopt the obvious criterion of energy, that is to say, if the strain energy of the slipped crystal is less than that of the unslipped, then slipping will occur. This is illustrated in Figure 3, where the form B will have much less energy than A.

The result of this argument is to explain why large metal crystals are so much softer than small, for a shear of one-half the atomic distance, measured

across the whole width of the crystal, suffices to produce slip, and for a thick crystal this is only a very small shearing strain. There is much else in Bragg's work beyond

Elasticity.—Before going on to other subjects, a general point in the theory of elasticity is worthy of mention. You will notice that I have been speaking entirely of shearing strains and stresses, and have made no mention of the much more familiar tensile ones. Tension can be much more easily measured and tested than pure shear, and it is often more important in structures, so the engineer tends to think much more about it. I want, however, to raise the question whether tension is not really a secondary thing in the theory of the strength of materials. You will recall that the elasticity of an isotropic material has two properties which can be defined in a variety of ways; for example, by giving Young's modulus and the shear modulus, by giving one of them and Poisson's ratio, or by giving one of these three and the bulk modulus—that is, the reaction to hydrostatic stress. From any two of these, the rest can be derived, and the only question is, which are the best to take? In other words, which are naturally the most primitive? A rather strong case can be made for taking the bulk modulus and the shear modulus as the two most primitive, since they correspond to the simplest types of strain which can be imposed on a solid body. In effect, this choice is made because it is easier to think of the stress as being called into play by an assigned strain than to do what is done in a testing-machine, which is to apply a given stress and see what the strain is. If, then, we are to start with strain as given, there can be no question that a linear tension is a rather complicated thing, involving as it does both a distortion and a change of volume.

This point of view derives from the classical theory of elasticity, and it is a very tentative matter to apply it to the question of ultimate strength. In the first place, some materials break in tension and others in shear, as is easily seen from the shape of the fractured surface. The strongest materials always break in shear, and it seems likely that this is the fundamental manner. I should conjecture that breaking in tension is really a secondary business. If a bar under test contains non-uniformities, there will result stress concentrations, and it is the shearing at these concentrations that causes the break. This is only a conjecture, but it leads to the plausible consequence that there is one cause, and not two causes, governing the strength of materials. Now I have pointed out that the classical theory of elasticity suggests that the bulk modulus is a more primitive thing than is Young's modulus, and this suggests that we should consider what is the "bulk strength" of materials; that is to say, the manner in which they yield under hydrostatic pressure or tension. We can immediately answer half this question, for there is no doubt that the metal, when hydrostatically compressed, resists that compression strongly and shows no tendency to break under it. As to its behavior under a hydrostatic tension, we can hardly give an answer at all, since it is impossible to apply such a system of forces to a solid. I know of only one experiment where something of the kind has been done. Ioffe took a sphere of rock-salt crystal (which is cubic and not far from isotropic) and immersed it in liquid air until it was all of one temperature. He then plunged it in hot oil so that the outer parts expanded, and these parts applied a hydrostatic tension to the inside, which was still cold. The tension showed no tendency to produce cracks. This one experiment is obviously a rather complex business, but it confirms a tentative conclusion that I wish to draw. The characters of solid matter may be divided into two types, namely, those sensitive to details of structure and those insensitive. All the elastic moduli are fairly insensitive, in that, for example, Young's modulus and the shear modulus are roughly the same for hard and for mild steels; but we know that the shear strength is sensitive. I want to suggest that what evidence there is points to the bulk

strength being insensitive to structure. If this is correct, then we have the simplification of theory that we can impute the structure-sensitivity of tensile strength to the shear strength. The advantage of this point of view is that we have only one quantity to consider which needs close examination, while the second elastic character plays little part in the consideration of strength.

Plastics.—After discussing the strength of metals, it would be natural to turn to the strength of other substances, such as plastics, but their composite structure makes this a troublesome matter, and there is not time to do more than touch on the subject. Roughly speaking, the plastic itself carries the shear, but the fibers the tension. Here there is a character very different from what I have just been discussing for metals, and it is attributable to the different nature of the chemical bonds. In metals, the unit is the crystal extending in three dimensions, whereas, in organic materials, the tenacity is provided by the bond between pairs of adjacent carbon atoms. This explains why they tend to form into chains rather than three-dimensional blocks, and hence it comes about that, for these fibers, tension is the fundamental quality rather than shear. However, without going into all this we can see fairly well that we cannot expect to get anything out of plastics for our present purpose. It is true that, weight for weight, plastics are about as strong as actual metals, but the metals are only one-hundredth as strong as they ought to be, and it seems most unlikely that we could raise a factor of one hundred for the plastics. I shall therefore not discuss them further.

Fluids.—After solids, fluids; but I shall touch on these much more lightly. The two main characters of a liquid are its compressibility and its viscosity. As to compressibility, there is little to be said. At the one end, we pass over into degrees of resistance to compression comparable with, but not so strong as, those of solids. At the other end we come up against the critical phenomena where liquid passes continuously into vapor, so that again there is no extreme property. Viscosity is more interesting. At one end we have highly viscous materials, such as treacle, then pitch, and then glasses, which shade into plastic materials and become indistinguishable from solids. I may also refer to those highly peculiar substances which appear quite stiff but gradually become liquid on stirring, and the converse ones which are liquid, but become stiffer and stiffer as they are stirred; but the theory of these is rather obscure and I must not attempt to discuss them. At the other end, that of small viscosity, there is much more interest in a particular substance which was discovered only a few years ago. This is liquid helium II. Helium is the substance with the lowest boiling-point of any, about 4 degrees absolute. Liquefaction was achieved in 1908. The next thing to do was to solidify it, but for long no success was achieved, until finally, in 1925, it was found that high pressure was essential, and that solid helium could exist only at a pressure of more than 20 atmospheres. But a much more remarkable thing was also found. At ordinary pressures, the liquid suddenly changes its character at about 2 degrees. Above this temperature, liquid helium I is a fairly ordinary fluid, with a density of about 0.1, and with viscosity and specific heat about the same as those of other liquids. At 2 degrees there is still no change in density or specific heat, but the viscosity drops to a very small value indeed and the heat-conductivity becomes enormous—one hundred times better than that of copper. That, at least, was how the matter appeared at first; but there was a good deal of discrepancy between the measures of various workers, and it was suspected that the viscosity was so low because, in every measure, turbulence had occurred, while measures of viscosity depend on using such fine tubes that turbulence is eliminated. Later work has suggested that the matter is not so straightforward, and, in fact, that the character of the substance is not to be explained in terms of the ordinary language used for liquids; but the business is by no means clear yet. We

may say, however, that a solid body could move extremely freely in helium II, and that it is practically impossible to keep bodies at different temperatures in its presence; and it has another remarkable characteristic; in that the liquid can creep over any surface in apparent defiance of the laws of hydrostatics, so that, if a tea-cup were filled with it, in a short time the liquid would appear in the saucer, and then on the table, and finally the level of the liquid would be the same all over whatever space was available.

Gases—When we come to gases there is little to be said, as the gas laws are very precise and admit of little variation. There are variations of equation of state near the condensation-point, but in the truly gaseous condition the only variety is in the density and the specific heat. The most interesting quantity is the ratio of the specific heats, which governs the law of adiabatic expansion, and the speed of sound, which is 5 : 3 for monatomic gases, 7 : 5 for diatomic, and still lower for more complicated molecules. We can say at once that 5 : 3 is the highest ratio that could ever be possible. With regard to density, we can say quite definitely that the limit of lightness is attained by hydrogen. Since we can number the elements from 1 to 92, and have samples of all of them (excepting one or two of the later ones which could not possibly be light), we know that there is no prospect of finding anything lighter than hydrogen. The only hope of improvement would be monatomic hydrogen gas, which would have half the density; but, though this gas can have a transitory existence, it combines rapidly into the diatomic gas with great evolution of heat—so great that it has been used for welding metals. I must, of course, qualify all these statements by demanding that the gas should be at normal temperature, for, by the application of heat, the density of any gas can be reduced without limit. But, as I indicated at the beginning, the lift of ordinary hydrogen is already 93 per cent of that of a vacuum, so that in no way could much improvement be won.

But, if I may extend the meaning of the word "gas," there are much more interesting things to be said. There does exist matter which is much lighter than hydrogen. This is the electron, which has a mass $\frac{1}{1840}$ of that of a hydrogen atom. Electron gas can have only a transient existence, because the enormous repulsive electric forces blow it to pieces at once; but we can take advantage of this transient existence in a more limited way. This is especially in connection with relays, which turn a weak cause into a strong effect. In a quick-acting relay, inertia is obviously of the chief importance in making a given force produce the quickest effect. The force on a body, which in the most delicate systems is almost always electric, depends on the electric charge, while the motion depends on the mass, so that $\frac{e}{m}$ is a measure of the capability of a system to act as a relay. The $\frac{e}{m}$ of the electron is 1840 times as large as that of the next best system, the hydrogen atom, and proportionately again better than that of heavier substances. It is this enormous factor that is responsible for the high qualities for amplification of the thermionic valve amplifier. We know of no reason or evidence that there is anything in the nature of a "sub-electron," so that we have arrived now at the ultimate limitation in relaying action by the use of the properties of a transiently-existing electron gas. It is true that there is a thing which is less heavy than electrons, and this is light itself, which carries energy but has no "rest-mass" at all. I have to word this carefully, because, in a wider sense, anything with energy has mass. But something

besides light must always occur in a relay, because at some stage the light has to be acted on or to act on matter with ordinary inertia. The efficiency of a relay is that of its heaviest part, and so we cannot hope by any means to improve on the electronic valve.

Although a free electronic gas can only exist transiently in a tube, there is an extended sense in which it is of much commoner occurrence; this is in the interior of a metal. Here there is a framework of positively charged atoms to neutralize the electron charges, so that the gas can now be permanent. Such a gas has certain properties which are entirely different from those of an ordinary one, a fact which was first recognized with the discovery of the New Quantum Theory, 15 years ago. The molecules of an ordinary gas are moving about with various and frequently changing velocities, and the frequency of occurrence of these velocities is governed by Maxwell's law of distribution, giving the average numbers at any instant with each velocity in the form of the well-known "cocked-hat" error law, the size of the curve depending on the absolute temperature. The electron gas has its velocities distributed quite differently. This is because of the Exclusion Principle, one of the basic principles of the Quantum Theory. I must not go into technicalities, but the rule is that two electrons must never be doing the same thing. Thus, if one electron is at rest in the metal, no other can be at rest; in an ordinary gas, there is no reason why many molecules should not be at rest simultaneously. There are a great many electrons in the metal, and they comply with all the conditions of low energy and many of the higher, so that a lot of them are forced to have quite a high energy. Instead of the Maxwellian figure we get, at ordinary temperatures, a curve with a very sharp fall to zero. The speed at this break corresponds to what in the other curve would be given at a temperature of about 10,000 degrees. To misstate it in picturesque language, the Exclusion Principle squeezes the electrons out of their rightful temperature; if the metal could be raised to 10,000 degrees without melting, then, for the first time, the electron gas would behave something like an ordinary gas. I wish I could enlarge further on this, but it is hard to do so without going more deeply into technicalities. Moreover, my main purpose in mentioning it at all has been because I shall want to return to it in the next subject for discussion.

Weight.—We have just been considering what is the lighest substance. It is natural next to ask, what is the heaviest. Forty years ago, the immediate answer would have been metallic osmium, which has specific gravity 22, and the only saving clause would have been that there might be other unknown elements which would prove heavier. We now know that there are no unknown elements, and yet we must answer the question quite differently. This is on account of certain very unexpected astronomical discoveries, made about 15 years ago. Certain stars were discovered which gave out light at a white heat and yet were very faint; therefore they were called "white dwarfs." The white heat implied a high temperature, and with this temperature they had no business to be faint; their faintness could only be explained by small size, and this implied a very high density. For example, the companion of Sirius is about the weight of the sun, but about the diameter of Uranus, and therefore its mean density must be about 50,000. At this density, 1 cubic inch of the material would weigh about 1 ton.

The general theory of these "dwarfs" is understood, though no one yet knows fully why they occur, and what happens to them ultimately. Their structure is an extreme case of the electron gas in a metal. In the interior of a star, the temperature is so enormous—millions of degrees—that the atoms lose most of their electrons, and this large number of electrons becomes subject to the Exclusion Principle. According to this principle, there is a simple relation between pressure and density which is independent of temperature;

it is the same relation as that which applies for the adiabatic expansion of a monatomic gas. So long as the temperature is not too high (and by high temperature I now mean something like one hundred million degrees), this relation holds, and implies that, under sufficiently high pressures, there is no limit to the density. As in most things of this kind, the result must not be pushed too far, because we have omitted certain secondary matters which ultimately become important. But there is good reason to believe that, in the deep interior of "white dwarfs," there are densities of something like 2 tons per cubic inch—specific gravity, one hundred thousand—which are maintained by pressures of the order of 1 million million atmospheres. It seems reasonable to hope that this is a final limitation on the density of matter.

Electrical Properties of Matter.—I will now turn to review the electrical properties of matter and their limitations. What is the best insulator we can hope for? Here the answer is fairly definite; we already have it in the form of good transparent crystals, such as quartz. The theory of insulators, as formulated nowadays, is curiously like that of conductors. The individual electrons in both are free to move about in the crystal, but the Exclusion Principle leads to an important difference. In the case of metals there is, so to speak, room for an electron to behave in a different way from what it is doing—not all the seats are occupied—so that it can wander about, carrying its electricity with it. In an insulator, there is a full house, so that, when one electron shifts its place, another is forced at once to take that place, and there can be no transport of electricity, and so no conduction. There are two ways in which insulators fail. Firstly, the surface often becomes covered with some foreign material, often merely water, which causes a leak over it. The second failure is much more interesting. One way of escaping from the rigor of the Exclusion Principle is to provide an electron with a good deal of energy, because then it can be "doing something different" from the others. If a crystal, say, of rock salt, is illuminated with ultra-violet light, some of its electrons absorb the light and acquire a high energy which sets them free to wander through the crystal. In this way, a conductivity not unlike that of electrolysis arises. To get a perfect insulator, this must be avoided, and it can best be done by keeping the crystal in the dark; since there is always radiation due to temperature, to make it very cold will also help.

At the other end of the scale, what is the best electrical conductor? Here also we can make a rather definite answer. The conductivity of alloys is worse than that of their constituent elements, both theoretically and in practical experience, so that we need only examine the table of the elements to see which is best. If we reckon by weight, this is sodium, but others are nearly as good. But a far more important question is the temperature. The conductivity improves with cold, and tends to very high values at the absolute zero. It is not certain whether it might not become infinite, but, as a general rule, there seems to be a small residual resistance. But the interest of this is very much diminished by the extraordinary phenomenon of super-conductivity. Certain of the elements—not by any means the best conductors at room temperature—and also some alloys and compounds, as the temperature drops suddenly, become perfect conductors; lead does so at 4 degrees K., so that, if a current is started in a lead ring below this temperature, it just goes on for ever—always provided the stock of cooling liquid lasts. This is a fascinating subject of study, not by any means cleared up yet, which possesses many of the characters of the older physics of Faraday rather than of modern atomic physics. I must not go into it now, but may say that there are pronounced limitations in its practical utility, because superconductivity is sensitive to magnetic fields, and fails when the field is strong; so that, if too great a current is carried by a superconducting wire, that current's own field destroys the superconductivity.

Magnetism.—The question of magnetism is also interesting because such great technical advances have been made in it lately. I can only touch on some parts of the subject, in particular on permeability and saturation values. Of these, the permeability at low fields is important for many purposes. The value for mumetal is about 60,000, and we may ask whether this could be increased. According to present ideas, iron and nickel have the property of being spontaneously magnetized in small domains, and all that the external field does at first is to turn the direction of spontaneous magnetization into another direction of easy magnetization. There does not seem any particular limitation on this process, so that (if we may leave out the troublesome practical questions of self-demagnetization due to the shape of the specimen) we can see no reason why quite a small field should not give practical saturation. Thus we know no reason why there should not be a better mumetal in the sense that the permeability for weak fields might be much larger; but, correspondingly, the exciting field would have to be reduced, or saturation would ensue. The question of magnetic saturation may be answered much more definitely, since there exists a fairly complete atomic theory. We can say that it is certain that nothing can show magnetic saturation per atom greater than five times that of iron, and it is extremely unlikely that anything will be found perceptibly better than iron. In this matter of saturation, we are not concerned with the ease or difficulty with which the magnetization can be set up. In iron it is spontaneous, whereas in some substances it calls for such strong external fields that nothing like the maximum has ever been attained. There is a natural unit of magnetization, the Bohr magneton, but theory indicates that there is no reason why an atom should possess an exact whole number of magnetons. Thus iron has 2·2, cobalt 1·7, and nickel 0·6. The largest number known is in the rare earth, europium, some salts of which have 10. This magnetization is in the salt, where the europium atoms are fairly far separated from one another, so that the total magnetization will not be very large. There is reason to think that it would not be so good for the metal, which is not spontaneously magnetic like iron anyhow, and that is why I said that there was very little expectation of getting anything better than iron.

Summary.—I have ranged over a wide field of properties of matter, and had better summarize them in conclusion. I am going to do so in a fanciful manner, by taking a structure built out of all the extreme materials I have imagined and seeing what it is like.

I propose to rebuild the ship *Queen Elizabeth*. My metal is one hundred times as strong as that used in the present ship. I do not propose to go into complicated questions of design; for example, the tension members can be immediately lightened one hundred times, but the thrust members will have to be much enlarged tubes in order to remain stable. I see no reason why I should not build the ship with one-hundredth of the weight of material. As the ironwork weighs something like 30,000 tons in the present ship, my ship will weigh only 300 tons. Therefore, to get the displacement, I shall have to ballast it with nearly 30,000 tons before I begin to put in the cargo. I immediately think of using material from a "white dwarf" star for this, and my ballast will then occupy about 17 cubic feet. However, I now notice that there will be technical difficulties in this way of doing things, since I should have to keep it at a pressure of one billion atmospheres and at a temperature of one hundred million degrees, so I give up this idea and fall back on ballast made of metallic osmium, of which I shall require as much as 50,000 cubic feet, say, a block in the form of a cube of 12 yards side. It is time now to attend to the machinery. Presumably, I shall think of putting in an atomic engine, but the trouble is that, whatever the engine itself may be like, so far as I can see, it will have ultimately to raise steam for a turbine,

so that my engine-room will still have to be quite large. For the auxiliary machinery, I will certainly take advantage of superconductivity, so that the wiring of the ship will be cooled by liquid helium; it must be made of tin or lead wire, since copper is not a superconductor.

This suggests a further flight of fancy. My ship on its journeys still has to contend with the resistance of the water. Would it not be more economical to alter the composition of the sea into something less resistant? If it is liquid helium II, I can economize in many ways. I shall need no special cooling for the superconducting electric wires. I can leave out nine-tenths of the ballast, since the density of the sea is now reduced to one-tenth. It is possible that I can give up having an engine altogether, by giving the ship a good shove at the start of the journey and receiving it on buffers at the end; I know too little about the real viscosity to judge of this. But the end of all my plans is tragedy. On account of another of its properties, the liquid helium II will irresistibly creep up the sides of the ship, over the bulwarks, across the deck, and down the companion ways, until it settles in the hold, in the effort to come to the same level inside as out. Deeper and deeper will grow the liquid in the hold, and deeper and deeper the ship will settle, until at last my imaginary ship will founder in the depths of the imaginary ocean!

OPERATION AND CARE OF BOILER CONTROL SYSTEMS.

The following article is divided into two parts, the first covering the combustion controls which regulate fuel and air supplies to the boiler furnace, and the second covering boiler feed and other miscellaneous controls used in the steam plant. The article was prepared by Mr. P. S. Dickey, Manager, Marine Department, Bailey Meter Company. It is reprinted from The Nautical Gazette, February, 1943.

Automatic boiler control systems have been used extensively in stationary power plants for the past twenty-five years. During the past five years increasing use of this equipment has been made in marine power plants, along with other improvements aimed at better economy and reliability.

More than two hundred ships now in service have automatic control in the boiler plant, and at least one thousand ships of our present building program will be equipped with automatic boiler control.

Proper use of automatic boiler control equipment greatly simplifies the operation of the steam power plant in addition to improving the overall economy, and therefore it behooves the operating personnel to become familiar with the function and care of these controls and keep them operating properly.

The following discussion will be divided in two parts, the first covering the combustion controls which regulate the fuel and air supplies to the boiler furnace, and the second covering boiler feed and other miscellaneous controls used in the steam plant.

Combustion Control.

FUNCTIONS.

To understand properly the operation of the combustion control system it is first necessary to be familiar with the functions which it is to perform. These functions are as follows:

(a) *Load Control.* The prime function is to supply fuel and air to the boiler furnace in accordance with the demand for steam for the main

engines and other plant machinery. Automatic regulation of the fuel and air supply eliminates the need for constant manipulation of the oil pressure or burners by the operators to maintain steam pressure.

(b) *Fuel Economy.* For most economical operation the fuel and air must be supplied to maintain uniform steam conditions, and in addition air must be supplied in proper relation to fuel.

The importance of close steam pressure and temperature regulation is clear when we consider that the overall efficiency of a turbine plant operating at 450 pounds pressure and 750 degrees will be reduced approximately one-half per cent for each twenty-five pound reduction in pressure, and one per cent for each twenty-five degree reduction in temperature. Furthermore, the maximum capacity available may be reduced in direct proportion to the reduction in steam pressure if a low pressure standard is maintained.

In addition, proper maintenance of the ratio of fuel and air supply to the boiler furnace is of utmost importance. For each furnace and fuel there is one best relation between the fuel burned and the air supplied for combustion. When air in excess of the proper requirement is supplied, fuel is wasted as a result of the heat carried away in this excess air, and this loss will average one per cent of the total fuel burned for each ten per cent of air supplied in excess of requirements. There is still a greater loss when less than the required amount of air is supplied for combustion, and this may be as high as ten to fifteen per cent of the fuel wasted for each ten per cent deficiency of the air supply.

(c) *Increased Furnace Life.* Steady regulation of the fuel supply and proper maintenance of the fuel-air relation will materially increase the life of refractory boiler furnaces. By dividing the load changes equally among all the boilers operating, load changes on the boilers are less severe and the furnaces are not subjected to as many damaging temperature shocks.

Regular cleaning and inspection of the oil burners likewise has much to do with furnace life, and regular inspection of the boiler auxiliaries is very helpful in getting the maximum possible service from these units.

(d) *Less Smoke.* When fuel and air are properly proportioned smoke will be eliminated, both during steady loads and maneuvering. In times of war this is of greatest importance. In times of peace absence of smoke is also important in keeping the ship clean and in reducing the amount of fouling in the convection heating surfaces of the boilers.

GENERAL DESCRIPTION OF COMBUSTION CONTROLS.

The method used in governing a steam boiler is not radically different from that of governing a steam engine or turbine. Steam pressure is used as the index of the relation between incoming and outgoing energy, and fuel and air supply is regulated to keep steam pressure constant.

However, in place of only one factor to be controlled there are at least three factors, namely, fuel, air and water supply, and these must not only be controlled to satisfy the demand, but the relation between fuel and air must be accurately maintained and the correct amount of water must be kept in the boiler. Likewise the various regulating devices for the fuel, air and water supply are not concentrated at one point, so that means for remote operation of these devices are necessary to centralize the control.

Compressed air is used in most cases as the actuating medium for marine combustion controls, principally because of the simplicity of the control equipment required and because there is no fire hazard involved in running compressed air lines to the various devices situated in different parts of the fire room.

Figure 1 shows a typical boiler control system as used on Types C1, C2, and C3 ships and tankers for the U. S. Maritime Commission and for a number of ships for private account. It will be noted that the following parts make up the combustion control system.

a. Master Steam Pressure Controller.
b. Air Relays.
c. Selector Stations for Remote Hand or Automatic Contro
d. Fuel-Air Ratio Controller (one for each boiler).
e. Power Devices such as piston operators for dampers, etc., and diaphragm motors for fuel-oil regulating valves.

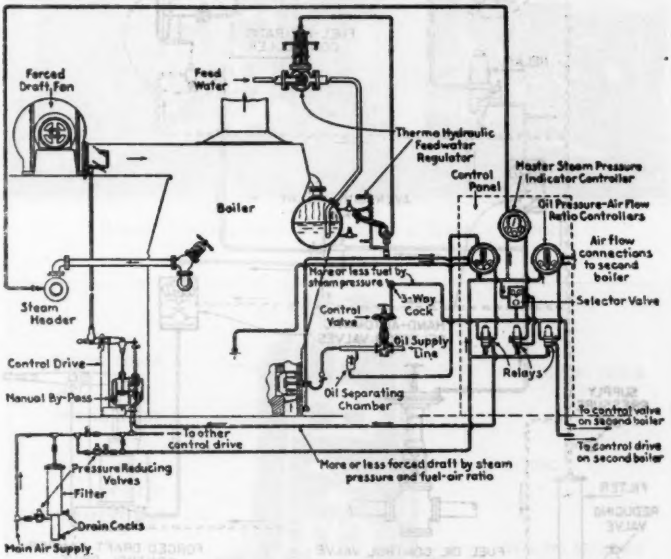


FIGURE 1.—DIAGRAMMATIC LAYOUT OF TYPICAL COMBUSTION AND FEED WATER CONTROLS.

All combustion control systems consist of similar units and there is no fixed rule for connecting up these various devices as the type of boiler and furnace, the type of fuel burning equipment and the arrangement of the fuel and combustion air supply systems determine which arrangement best suits the particular plant. Four arrangements often used are as follows:

1. Series control. Steam pressure adjusts the fuel rate. Measured indication of fuel rate establishes a metered air flow.

2. Series control. Steam pressure adjusts the combustion air flow. Measured indication of air flow establishes a metered fuel flow.

3. Parallel-series control. Steam pressure adjusts the fuel rate and combustion air flow simultaneously. Metering type fuel flow—air flow ratio controller readjusts the fuel flow.

4. Parallel-series control. Steam pressure adjusts the fuel rate and combustion air flow simultaneously. Metering type fuel flow—air flow ratio control readjusts combustion air flow.

Figure 2 shows a line diagram of the parallel-series control system (No. 4) which is most commonly used and is illustrated in Figure 1.

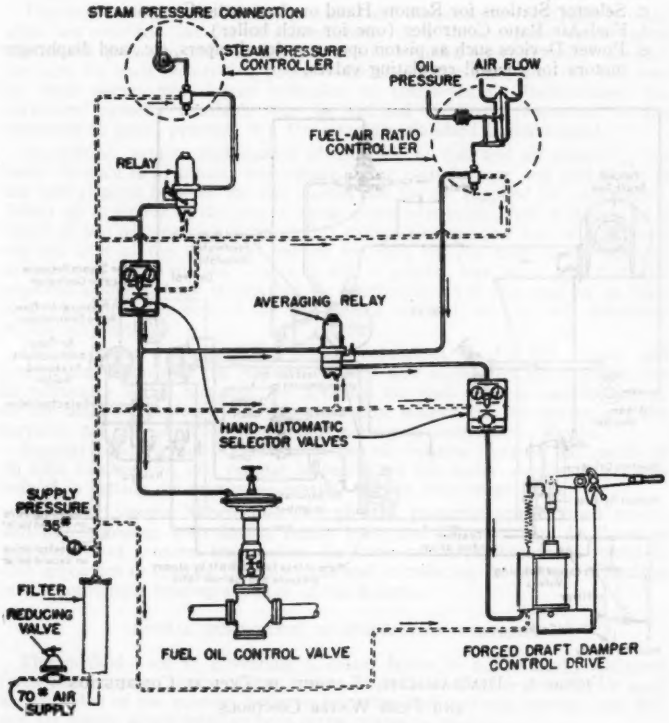
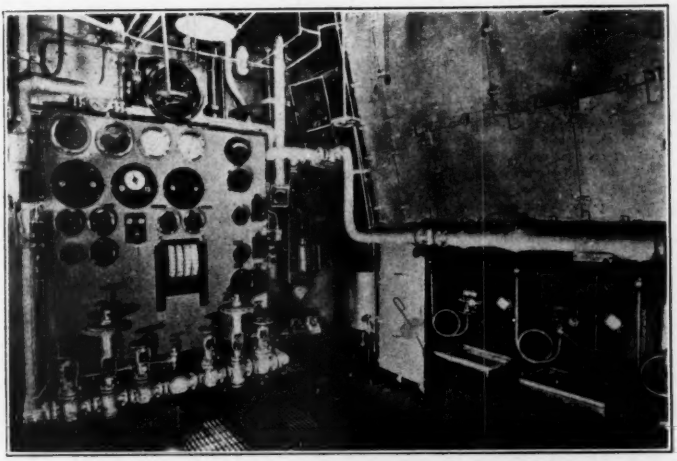


FIGURE 2.—PARALLEL-SERIES CONTROL SYSTEM.

COAL BURNING BOILERS.

When coal is applied to boilers fired by coal on spreader type stokers the arrangement of the control is similar to Figure 2 except that a piston operator actuates the stoker speed control in place of the diaphragm motor which actuates the oil valve. The fuel-air proportioning controller measures and controls from the relation of steam output and combustion air flow in place of fuel oil flow and air flow. Many of these boilers are also equipped with induced draft fans and a separate controller actuates the induced draft fan control and uptake damper, or both, to maintain a constant suction in the furnace.



Boiler Control Installation on a Modern Tanker.

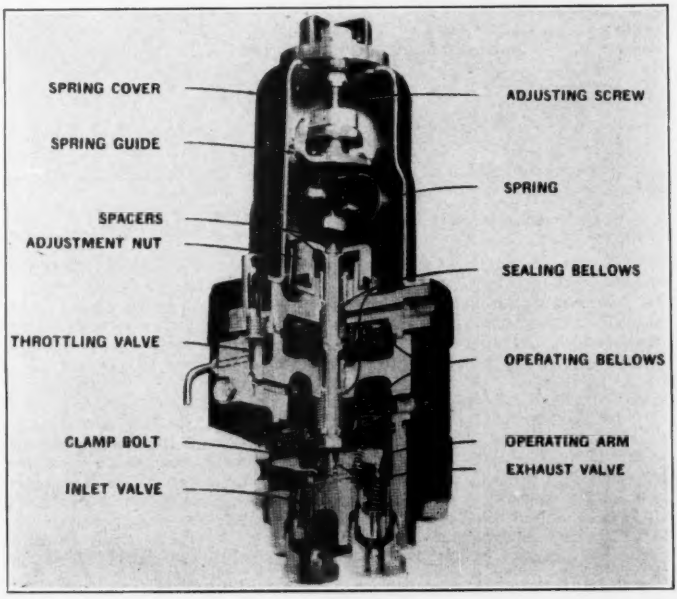


Figure 4.—Air Relay.

GENERAL DESCRIPTION OF CONTROL UNITS.

(a) *Master Pressure Controller.* This controller shown in Figure 3 consists of a Bourdon tube or other type of pressure responsive device which actuates an air pilot valve to develop an air loading pressure proportional to steam pressure changes. The controller is ordinarily provided with Range adjustment so that the increment of steam pressure change for full stroke of the controllers may be adjusted to suit each particular installation. Likewise a Standard adjustment is usually provided to allow the controller to be adjusted to maintain any desired steam pressure.

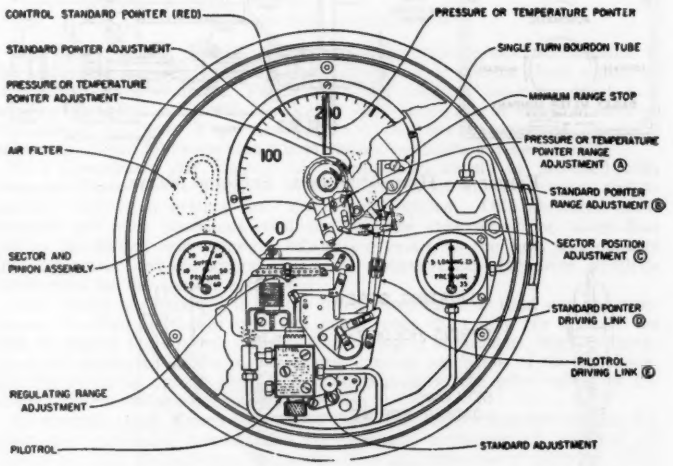


FIGURE 3.—MASTER STEAM PRESSURE CONTROLLER.

(b) *Air Relays.* Their air loading pressure developed by the Master Pressure Controller is transmitted usually through ¼-inch O.D. copper tubing to air relays as indicated in Figure 4. These relays are used for amplification or may be used for adding, averaging, or reversing air loading impulses, or may provide standardizing or accelerating action. Compressed air at the supply pressure is connected to the inlet valve of the control chamber D.

(c) *Selector Valves.* The air loading pressure from the relays is transmitted to the hand automatic selector valve, similar to Figure 5, which consists of a relay and cam-operated shutoff valves. This unit is arranged so that in the automatic position the air loading impulse is duplicated and transmitted to the various control drives. A manual position is provided in which the incoming air loading impulse from the controllers is cut off and any desired air pressure can be established by manual adjustment of the load adjusting knob. Thus the position of the various control drives can be established remotely and the gage on the selector valve indicates the position of the drive.

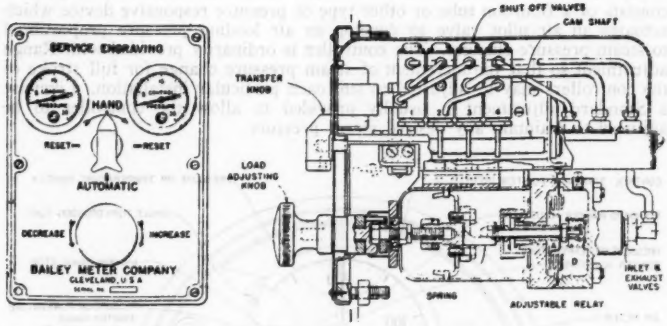


FIGURE 5.—HAND-AUTOMATIC SELECTOR VALVE.

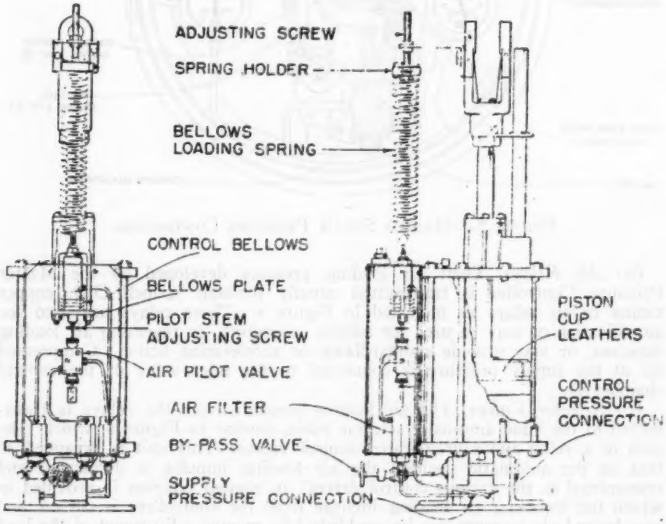


FIGURE 6.—AIR-OPERATED CONTROL DRIVE.

(d) *Fuel-Air Ratio Controllers.* Fuel-Air Ratio Controllers measure the combustion air flow and either the fuel oil flow or the boiler steam flow, and from the ratio of these two flows an air loading pressure is developed to readjust one or the other of these factors to maintain the proper excess air for combustion.

(e) *Power Units.* Power units consist of double acting air cylinders similar to Figure 6, or spring-loaded diaphragm motor operated valves. The air cylinders are equipped with positioning relays by means of which the four-way air valve connected to the two ends of the cylinder is adjusted to insure a definite position of the piston for each incoming air loading impulse pressure.

CARE AND MAINTENANCE.

The boiler control system will require very little regular maintenance if the equipment has been carefully installed, and if a suitable clean source of compressed air is available. Pneumatic controls have a minimum number of wearing parts and satisfactory service for many years can be expected without replacement of parts if no unusual conditions are encountered. Regular inspection of the following items is advisable to insure the best results.

(A) *Compressed Air Supply.* Air compressors should be provided with adequate filters on the intake to improve the life of the compressor and to prevent dust from getting into the control system. Oil lubricated compressors are most commonly used and extreme care should be taken that neither insufficient nor excessive lubrication exists, as the first will damage the compressor and the second will cause excessive oil carry-over which is detrimental to the control equipment.

Best results are obtained if a slow speed compressor is used and the compressor is sized so that it need not pump more than fifty per cent of the time to supply the control system. If pumping is continuous, high temperatures are generated in the air cylinders, causing oxidation of the lubricant, and the resulting vapors and sludge will deposit in the pilot valves of the control system and require periodic cleaning.

In general, steam driven locomotive type compressors are not suitable for operating pneumatic controls due to excessive carryover of oxidized oil caused by high temperatures encountered in the compressor cylinder. This type of compressor should be installed for emergency service only.

Best results are obtained if the intake for the compressor is taken from a cool and dry place so that a minimum amount of water is carried in the air. Likewise the air receiver and all low points in the compressed air headers should be provided with traps and drains, and the condensation at these points should be blown out regularly.

The main filters for the supply to the control system should be inspected each six to twelve months and new filtering mediums installed if necessary.

(B) *Connecting Piping.* Two general classifications of connecting lines are used with the control system. The first being the pressure or differential pressure connections to metering or control units and the second being the piping used for transmitting the compressed air supply and the compressed air loading impulses of the control system.

In order that the control system function properly, it is essential that both classes of piping be free of leaks and free of any restrictions as may be caused by metal chips, dirt, oil and water or any combination. If during installation pipe connections have been run in an orderly and workmanlike manner, and the piping properly supported, it is likely that joints have also been properly made and will not cause trouble. However if pipings have been run in a sloppy manner and not properly supported, leaks at the various joints can also be expected and the piping should be completely and care-

fully checked for leaks after a short period of service. Brushing the joints of the compressed air piping with a soapsuds solution will quickly reveal any leaks.

Connecting lines are less subject to stoppages if all horizontal runs are made with a slope of at least one inch to the foot, and if settling chambers are provided at the low points of the lines with blowoff valves at the bottom of the settling chamber.

The following schedule should be adhered to in keeping connecting piping clear:

(1) Steam pressure connections should have a five to ten second free blow under line pressure every three months to clean out any sludge in the line.

(2) Draft connections from the boiler to gauges and controllers should have a free blow lasting at least one minute every three months. Use air at least fifty pounds pressure. The lines should be disconnected from the controllers to prevent damage to any sensitive diaphragms and should be blown from the controller end of the line back to the boiler.

(3) Pressure connections made to fuel oil piping should be filled with Prestone, Ethylene Glycol or Glycerine to avoid sluggish response of gauges or controllers due to congealed oil in the connecting piping. Separating chambers with try-cocks are usually provided at the oil line connection and the piping should be checked every three months to make certain that the separating chamber and connecting lines to the gauge or controller are filled with the sealing fluid.

(4) Settling chambers in the compressed air piping and drain cocks on the compressed air receiver and filter housings should be blown free of moisture at least once each day.

CONTROLLERS.

Controllers will require very little maintenance if the source of compressed air is clean and if connecting lines are kept clean in accordance with the program outlined above.

The stems, seats, and ports in the air pressure reducing valves, the pilot valves and the relay valves may require periodic cleaning if the compressed air supply is not properly filtered, and if excessive carry-over of oil is obtained from the air compressor. Before attempting to disassemble or clean any part of the controller, always read the manufacturer's instruction completely and carefully so that the correct procedure will be followed.

Air cylinders should either be lubricated with a light grade of mineral oil every three or four months, or they should be dismantled and greased with brake cylinder lubricant every six months to one year. In the latter case no oil is used.

Linkage between the air cylinders and the dampers, rheostats or other devices being controlled needs regular inspection and lubrication. Where cable drives are used (even though not generally recommended by the manufacturers), these cables must be even more frequently inspected and adjusted, as most cables are subject to stretching in service.

Damper blades and bearings, rheostat bearings and brushes, turbine valve gearing and other devices actuated by the cylinders should have regular inspection to see that these devices are functioning properly and that they are operating through the proper range for full stroke of the operating cylinder.

In general, best results will be obtained with the control system if the original adjustments are not changed. Ordinarily, the manufacturer's representative leaves with the ship or with the shipyard a complete record of the various adjustments found to give best operation of the control, and

these adjustments should be maintained. Never experiment with the adjustments of controllers, relays or power devices without first making a careful and complete study of the manufacturer's instructions covering the unit.

OPERATING PRECAUTIONS.

In the operation of oil-fired boiler furnaces whether or not they are equipped with automatic control, the following precautions are necessary to insure safe and efficient operation:

When lighting off make certain that:

(a) The furnace is purged of all fuel.

(b) Ample torch flame is properly applied to each burner before fuel is turned on to each burner in succession.

(c) Air velocity at each burner is kept low enough to prevent blowing out the flame.

(d) Fuel is supplied in a sufficiently rich mixture to ignite immediately from the torch.

For best operation under automatic control:

(a) The oil burners must never be allowed to operate below the minimum oil pressure specified by the manufacturer. Do not fail to reduce the number of burners in service when the oil pressure approaches the minimum specified.

(b) Always use the same number or size of burner tips with all burners operating in the same furnace. Never throttle individual burner oil valves while the burner is in service.

(c) When blowing soot it is usually advisable to increase the excess air either by placing the draft controller on manual control, or by increasing the excess air adjustment of the fuel-air ratio controller.

BOILER FEED WATER CONTROL.

Regulation of feed water to the boilers is not a particularly difficult job, but one which is so important to continued operation of the plant that only the most reliable types of automatic regulators can be used for this job.

In the modern steam plant using water tube boilers and using feed water heaters or economizers, it is important that the feed water flow be steady and approximately equal to the steam output. Severe cycling of the feed water flow may result in cycling of a number of other auxiliaries and may cause appreciable reduction in overall plant efficiency.

Cycling action of the feed water control is usually caused by surges in the water level in the drum ordinarily due to variations in the volume of steam below the water line. The amount of surge is influenced by the operating pressure, concentration of the feed water, the arrangement and effectiveness of the circulating system in the boiler and the amount and arrangement of the steam liberating surface in the boiler drum.

Two general classes of feed water regulators are ordinarily used on marine boilers. The first is the self-actuating type which consists either of a thermal unit or a float connected to the drum, and this unit furnishes sufficient power for operation of the feed valve. The second unit is the pilot operated type which consists of a level responsive device which is connected to the drum and which actuates a pilot valve which furnishes the pressure which actuates the diaphragm motor valve in the feed line.

DIRECT ACTING TYPE.

The direct acting regulator type consists of a thermo-hydraulic generator with connections above and below the water line of the boiler drum to the inner tube of the generator assembly. A second finned tube is mounted

around this inner tube, forming an annular pressure chamber which is heated by the steam above the water level in the inner tube (which is at the same level as that in the boiler drum). This annular chamber is filled with water when the valve is closed, and as the water level in the boiler drops, heat is transferred from the inner to the outer chamber and sufficient pressure is generated in the outer chamber to open the bellows operated valve. The valve will open until the level in the outer tube is approximately equal to the water lever in the inner tube.

The action of this thermo-hydraulic generator thus provides full throttling action of the regulating valve so that water flow is regulated approximately in accordance with steam output, and continual overfeeding and underfeeding is avoided. The restoring action of the water level in the outer tube of the generator provides additional pressure, and thus extra power for positioning the feed valve in case any friction is present.

Regulating valves for this type of regulator are usually of the balanced double-seated type. This double-seated type of valve is used to keep the size of the seats and plugs as small as possible and to balance the forces due to the pressure differential, so that an operating bellows and spring of reasonable size can be used.

This type of valve is provided with an internal cage into which the valve ports and seats are fabricated. The use of this cage construction eliminates the possibility of distortion of the seats with pressure and temperature changes in the body casting, and also makes it possible to remove easily the inner valve parts for inspection and regrinding on a bench.

PILOT-OPERATED REGULATORS.

Where there is a reliable supply of compressed air available the pilot-operated feed water regulator has many advantages. A typical example is well illustrated, perhaps, where reciprocating feed pumps are used and the stroke of the pump pistons is adjusted to regulate the water flow. Installations of this type are usually equipped with a spare steam-driven pump, and the feed water control must be arranged so that it can readily be shifted from the motor-driven to the steam-driven pump. Since the equipment required for accomplishing this result with the direct acting regulator would be cumbersome, the pilot-operated regulator is normally used.

The regulator consists of a level responsive device which operates an air pilot valve to develop an air loading impulse in accordance with drum level. This impulse is transmitted through the necessary relays and through a hand-automatic selector valve to the diaphragm motors, which in one case actuates the stroke adjustment of the motor driven pump, and in the other case actuates a valve in the steam line to the steam driven pump. Shutoff valves are used in the compressed air loading lines to the diaphragm motors so that either unit may be actuated from the level controller.

Several different types of level responsive devices are used with this regulator, including the thermostatic type used with the direct acting regulator and also the thermostat type which is similar to the thermo-hydraulic except using a bimetallic element for actuating the pilot valve, float operated units and bellows actuated units. Some of these level responsive devices have the advantage that they indicate level in addition to operating the pilot valve and the indicator may be located some distance from the drum so that it can be installed on the boiler control panel and thus provide a guide to the water tenders which is both easier to read and which is available in case the gauge glass should be broken.

MISCELLANEOUS CONTROLS.

In many cases automatic controls and regulating valves similar to those described above are used for maintaining the level in heaters and other

tanks. Likewise many temperature and pressure controls use similar equipment and if the operator becomes completely familiar with the operation and care of the boiler controls he will be able to take care of these other miscellaneous controls used to simplify the operation of the plant.

Operation and Care

CONTROLLERS.

Level responsive devices and the connecting piping between these units and the boiler drum or tank in which the level is being measured require regular attention to insure most satisfactory performance. The connecting piping must be kept free of sludge to insure accurate and reliable response to level changes. Frequent blowdown is necessary to prevent sludge accumulation.

Thermo-hydraulic or thermostatic level measuring devices connected to the drum will become sluggish in operation if air is allowed to accumulate in the water and steam space. Periodic blowdown is necessary for the removal of this air and a free blow of from five to ten seconds duration is necessary to insure purging of the air.

In view of the above it is advisable that all level responsive controllers be inspected and blown down on a definite schedule once during each twenty-four hours of operation and at any time that the plant is being placed in service.

Thermo-hydraulic regulators must be inspected regularly to make certain that no water is lost from the closed system formed by the outer tube of the generator, the connecting line and the diaphragm motor or bellows which operates the feed valve. To check this level, close the shutoff valves and open the blowdown valve. After the generator has cooled down, remove the filling plug and make certain that the level of water is up to the filling plug.

Differential bellows type level indicators must be treated with care when taking them out of service for blowdown or inspection. Since the bellows usually cannot stand full line pressure on one side only, it is essential that the equalizing valve be opened whenever either of the differential pressure connecting lines is shut off. Likewise when placing an indicator of this type in service, the equalizing valve should be opened when line pressure is applied to the unit from one of the differential pressure connections. As soon as the unit is filled with water and under pressure, vent any air from the pressure housing, and then close the equalizing valve and open the second differential pressure connection.

For pilot-operated controllers, follow the instructions given under Combustion Control for maintenance of the compressed air system and the air valves and relays.

REGULATING VALVES.

In order to achieve the smooth flow regulation desired, regulating valves often have restricted port openings and are manufactured with relatively close clearances. Unless the piping in which the valve is installed is thoroughly cleaned during erection, or unless strainers are provided ahead of the regulating valve, difficulties may be encountered due to seizure of the inner valve caused by an accumulation of metal chips or other foreign material carried through the pipe line and into the valve.

If the piping is not thoroughly cleaned during erection a wise policy is to remove the inner valves from all regulating valves during the boiling out and preliminary operating periods. Most of the foreign materials will then accumulate at low points of the line and can be removed before doing any damage to the inner valves of the regulating valves.

If this precaution cannot be taken, due to lack of time or for some other reason, regulating valves should be opened up after the preliminary operating period, and the inner valves inspected and any foreign materials which have collected in the body should be removed.

In general, the inner valves of regulating valves are made of the very best materials available considering the service and justifiable cost. These valves are, however, subjected to severe working conditions, and if good regulation and shutoff are desired, the valves should be inspected and reseated periodically. Ordinarily all regulating valves should be inspected and, if necessary, reseated at least once a year.

To avoid leakage and to insure against damage to the inner valve parts it is essential that the seat ring assembly be anchored securely to the valve body. If a suitable wrench is not available, then a special wrench should be built and retained for this service, so that the inner valves may be anchored securely in the body and removed without damage.

Stem packings require more frequent attention on regulating valves than on shutoff valves because of the necessity of keeping friction at a minimum. Only packings made of inert materials should be used so that there will be no corrosion of the valve stem. Nearly all packings become hard after a reasonable period of service and will then require a tight gland to prevent leakage. Periodic replacement of the packing will keep the material soft and permit a leak-proof gland without excessive friction.

Diaphragm motors and bellows operators for regulating valves will give reliable service over long periods of time if not subjected to excessive pressures or other unusual conditions. Fabric diaphragms coated with rubber or other synthetic materials generally should not be subjected to temperatures in excess of 150 degrees F., and therefore the valves should be located at a point where the ambient temperature is reasonable and where they are not subjected to radiant heat of the furnace or other hot objects. Metal bellows or diaphragms must be operated within the range of travel for which they were designed if satisfactory life is to be obtained. If the diaphragm is disassembled for inspection or repair, extreme care should be used in reassembly to make sure that the bellows or diaphragm operates over the proper range.

Guide bearings should be examined periodically to make sure there is no excessive friction. A common difficulty encountered is friction in the guide bearings due to careless painting. A mixture of graphite and oil applied to guide bearings and the valve stem is often helpful in minimizing the friction.

GENERAL.

Best results will usually be obtained if the responsibility for the boiler control and other power plant controls is given to one man. The various controllers used around the power plant will have many common design features, and in many cases are so similar in construction that one man can rapidly become familiar with all of them. Frequently more harm than good is done by persons not familiar with apparatus and not provided with instructions when repairs are attempted.

If one man is made responsible for the controls, more reliable operation will result and unnecessary maintenance and repairs will be avoided. If difficulties are encountered which cannot be cleared up with the ship's facilities, a manufacturer's representative is usually available at most American ports of call. The manufacturer's service engineer can analyze and remedy the trouble much faster if there is one man on the ship who can give a complete and clear report regarding difficulties encountered.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

REPORT ON 1200-POUND REHEAT MARINE INSTALLATION.—In 1941, Benjamin Fox and Richard H. Tingey, of the Bethlehem Steel Company, Shipbuilding Division, presented a paper before the Society of Naval Architects and Marine Engineers describing the machinery installation of the American Export Line SS. *Examiner*. Following a period of service of the vessel and subsequent study of that experience, the authors presented a brief supplement to their 1941 paper suggesting interpretation of those results. This condensed version of their paper is reprinted from the Marine Engineer (Steam Number), May, 1943.

The *Examiner* went into service on a foreign run early in 1942 and had been operating seven months before returning to a United States port. Throughout this period the vessel was out of close contact with the owner's shore organization and therefore her engineers were essentially on their own. Great credit is due the engineering personnel of the ship for overcoming the initial troubles inevitably associated with an experimental power plant, especially under the unusual difficulties associated with war conditions. The operating experience and performance on this voyage merit close scrutiny.

During the trials and subsequently in service some machinery difficulties were encountered and corrective measures were taken as described in the following:

On trials it was found necessary to reduce the reheat to about 680 degrees F. to maintain a practicable division of load between the superheat and the reheat furnaces; under these conditions the superheat was only 685 degrees F. After the trials some surface was added to the primary superheater, some baffles were installed to prevent by-passing and the water screen tubes were respaced to make the primary superheater and the reheater more effective. These changes improved the superheat and division of load only a little and, as there was no time to make any further changes, the ship has been operated at reduced superheat and reheat in service. When the ship becomes available long enough to make such changes, the secondary superheater surface will be increased and made more effective. This is expected to bring the superheat and reheat to approximately 740 degrees F. and to produce a satisfactory division of load between the two furnaces.

The most serious difficulty encountered with the boilers was leakage through the superheater handhole gaskets. Whenever the boiler was brought up to pressure and put on the line after being out of service for some time, many of the superheater handholes leaked. It was found necessary to reseat all of the handhole faces during the first trip and great care had to be taken in putting the boiler on the line, tightening the handhole covers frequently as the pressure was raised. The handhole facings have been carefully remachined and a modified type of flexitallic gasket has been installed. All superheater handholes will be eliminated from the new secondary superheater which is to be installed to correct the unbalanced load condition and blind nipples will be rolled in instead.

There was one boiler tube failure in the fire row and two other tubes were badly blistered in service. These failures were due to low water level.

The economizer consists of hairpin tubes having individual return headers bolted against the tube ends with soft iron gaskets in the joints. Immediately after delivery many of these joints leaked and it was found necessary to reface the tube ends and remake the joints before the first voyage. During the voyage a joint at the economizer distributing manifold leaked. It was found to have a faulty gasket, which was replaced. Since then these joints have given no trouble.

During the first two trials the observed pressures in the high-pressure turbine departed materially from the expected values and the water rate was somewhat higher than expected. The high-pressure turbine was opened and some corrections were made to the nozzle areas and the clearances. These changes partially corrected the pressures and improved the water rate 3 per cent.

After running about 23,000 miles, mostly at normal power, a casualty occurred to the high-pressure turbine. When operating at 85 Rpm. the shaft revolutions suddenly dropped to 75 per minute without any other outward manifestation of trouble. It was then noticed that the pressure at the inlet to the high-pressure second stage had gone up to boiler pressure very suddenly and that the intermediate-pressure turbine inlet pressure had dropped very low. This indicated a constriction in the high-pressure turbine which reduced the flow to the intermediate-pressure and low-pressure turbines. The ship was operated this way for about another day, due to war conditions, when a slight noise was heard in the high-pressure turbine and its thrust bearing began to heat up. Later in the day the engines were stopped and the high-pressure and intermediate-pressure turbines were disconnected. The emergency piping was fitted and the ship proceeded to port using the low-pressure turbine only. The high-pressure turbine casing was lifted and it was found that the blading of the fourth and fifth stages was badly mutilated and that the corresponding nozzles were practically closed. The damaged fourth, fifth and sixth stage diaphragms were removed and the blades of the fourth and fifth stages were machined off flush with their roots. This work was done by the ship's force on the ship's lathe. The high-pressure turbine was then reassembled and the vessel proceeded homeward taking steam through all three turbines in the usual manner. It is the opinion of all concerned that a piece of shrouding came off the fourth stage blading and initiated all of this damage. New blading and diaphragms have been installed; the weight of shrouding and number of blades per segment were altered slightly; and additional precautions were taken in welding the shroud to the blade tips.

In addition to opening the high-pressure turbine to repair the damage sustained at sea, the intermediate and low-pressure turbines were opened in accordance with the owner's practice to inspect the first turbine of each class after about a year's service. The intermediate-pressure and low-pressure turbines were found in good condition except that some blade roots in the intermediate-pressure cylinder were found loose and were recaulked. No difficulty attributable to the high-pressure or reheat piping or equipment was experienced in opening the turbines.

Originally, emergency connections were provided to run the low-pressure turbine alone with the high-pressure and intermediate-pressure disconnected or to run the high-pressure and intermediate-pressure alone with the low-pressure disconnected. Additional piping has now been provided to permit running on the intermediate-pressure and low-pressure with the high-pressure disconnected. This will permit operating at about 75 per cent of full power in case of damage to the high-pressure turbine.

The feed control system for the reciprocating pumps consists of a pressure regulator which varies the stroke of the pump to maintain constant discharge pressure, and a boiler level regulator which throttles the flow to the boiler. As the action of the level regulator is much faster than the pressure regulator, an automatic by-pass valve is fitted on the pump discharge to take away the excess feedwater for the short time that the pressure regulator takes to adjust the pump stroke to the new feed requirements. Relief valves also are provided on the pump discharge to prevent building up excessive pressure in case this by-pass valve does not properly limit the discharge pressure.

The automatic by-pass valve did not perform satisfactorily on the trials and it was found necessary to make some changes in its design which were accomplished just before delivery. This valve gave further trouble in service and was shut off from the feed line.

Therefore the pump relief valves took over its functions and, as they were not suitable for such frequent service, their seats were destroyed in a short time. Furthermore, they did not limit the discharge pressure to as low a pressure as would be desirable. Under these conditions the ship's force put the control devices out of action, and manipulated the feed pump stroke manually. This was not very satisfactory as it was impossible to prevent excessive pressures building up momentarily. Steps have been taken to correct these faults, which are not fundamental to the system but are matters of detail design.

The ship has been returned to service after these corrections were made and has proceeded on her second voyage.

All of the equipment and functions relating to the reheat system were entirely free from trouble and no difficulty was encountered in the operation of the reheat system. The special provisions for drainage of the reheat piping were found adequate and reports of the condensation observed indicate that probably they were necessary. The high-pressure steam piping and joints were entirely free from trouble. Immediately after delivery, two joints in the feed system leaked and it was found necessary to remake them before the first voyage. However, the accessibility to these two joints, which were in a congested spot, was poor and it is believed that they were not properly made up in the first place. Access to the joints was improved in order to insure that they would be made up properly and since then they have given no trouble.

The reciprocating feed pumps have been used continuously at sea except when it was found necessary to shut them down to repack the glands, as happened frequently. During these shutdowns the turbine-driven pump was used and it performed very satisfactorily. It is expected that the reciprocating pumps will not have to be repacked as frequently when the feed by-pass and relief valves have been properly adjusted to prevent excessive pressures on the pump.

At sea, the turbo-generator was operated on bleeder steam as was intended and the automatic change-over devices, which put this generator on live steam when the main engines are slowed down, have been used continually and have always worked satisfactorily.

The 1200-pound pressure-reducing valves which are of the air dome type have been very satisfactory. Combustion controls have given no trouble whatever in service and the air puff soot blowers performed very well.

Fuel Performance at Sea.

In the original paper the expected fuel performance of the *Examiner* was expressed in oil per shaft horsepower for all purposes. This is of course the only proper criterion of the fuel economy of the machinery and should be used whenever the shaft horsepower is known. In sea service, however, the shaft horsepower is not measured. While approximations may often be made from nozzle pressures and steam and exhaust conditions the data available in the engineer's logs are not usually sufficient to provide a dependable value for the shaft horsepower. It is customary therefore to ignore the shaft horsepower and to make the comparison on the basis of other quantities that are known accurately.

Table I contains data derived from the service logs of the *Examiner;* also corresponding data from the service logs of the *Exchange* which is one of the 425-pound installations of the *Exporter* class. Inasmuch as the various

legs of voyages of the two vessels were run at somewhat different displacements and speeds the fuel consumptions have been reduced to a fuel coefficient defined by the formula: $C = \frac{\triangle\ 2/3\ V^3}{\text{long tons per day}}$

TABLE I.

No.	Item	*Exchange*, 425 lb. installation	*Examiner*, 1200 lb. reheat installation
1.	Period covered	March, 1940 to Feb., 1942	Feb., 1942 to Sept., 1942
2.	Total distance travelled, nautical miles	141,847	30,300
3.	Distance used in the fuel comparison	140,967	14,247
4.	Average time out of dock for the voyage legs in (3), days	57	113
5.	Average speed, knots	16.35	15.85
6.	Average displacement, tons	13,800	15,300
7.	Average slip (apparent), per cent	4.7	7.9
8.	Average fuel coefficient at the average speed and displacement	56,300	62,100
9.	Per cent improvement of *Examiner* over *Exchange*		10.3

The factors of this coefficient are easily determined with ample accuracy from the ships' records; and they are used without corrections of any sort. Weighted averages are obtained by using total distance and total time for average speed, and total fuel and total time for average fuel rate.

In using the data from the logs we have discarded voyage legs where the speeds were less than 15 knots, because they usually represented abnormal operation such as sailing in convoy or in extremely rough seas. In the case of the *Examiner* all fuel data taken after the occurrence of the turbine trouble were also discarded, as they would have no bearing on the comparison. With the exceptions noted, the table represents, to date, the average service fuel performance of the two vessels.

In item 4 of the table it will be noted that the average time out of dock for the *Examiner*, on the voyages used, was roughly twice that for the *Exchange;* also that the average apparent slip was 3.2 per cent greater notwithstandng the fact that the propellers are duplicates. Only a portion of this increase in slip can be explained by the increased displacement; the remainder must be due to other conditions that tend to make the ship require more horsepower, including sea conditions and foul bottom.

In item 9 of the table the improvement of the fuel coefficient of the *Examiner* over the *Exchange* is 10.3 per cent. Under equal sea conditions, as previously explained, the improvement undoubtedly would have been somewhat better. In view of the nature of the data this is considered a good enough confirmation of the predictions.

Conclusions.

Fuel Economy. The service performance data confirm the improvement predicted for the high-pressure reheat cycle compared with the normal cycle at 425 pounds per square inch and 740 degrees F.

Space. Experience has shown that the space provided for the 1200-pound reheat installation, which is the same as that provided on the other ships of the class having 425 pounds, 740 degrees F. machinery, is entirely adequate. The slight increase in congestion and decrease of accessibility, mentioned in the original summary, caused no inconvenience in service; and the reheater piping imposed no burden on operation and overhaul.

Operation, Maintenance and Reliability. The authors have reported herein every pertinent detail as to machinery troubles. While these were relatively serious and burdensome, they all appear to have been due to mechanical inadequacy and to be capable of complete correction through minor detail changes. It is quite apparent that none of the difficulties was related to the use of the reheat cycle and that those due to high pressure were not unavoidable.

The engineering crew on the *Examiner* included three firemen more than the crews of the other vessels of the class. This precautionary measure was taken by the owners so that the new experimental machinery could receive more than usual attention until the "bugs" were ironed out. Operating experience indicates that when the experimental stage is passed there will be no need for more personnel than on any other steam vessels. The ship's engineers say that, except for the mechanical troubles outlined herein, the operation of the machinery did not require more attention than the other ships of the class.

Weight and Cost. Service experience affords no additional information as to weight and cost.

General Conclusions. The service experience of about seven months shows good promise but more operation is necessary before final conclusions should be drawn. However, based on the knowledge now available, the authors suggest the following:

The high-pressure reheat cycle should be given consideration in future merchant practice. In a vessel of the power of the *Examiner* (8000 S.H.P. normal) the improvement in fuel of 1200 pounds, 740 degrees F. gas reheat compared with the 425 pounds, 740 degrees F. cycle will be about 13 per cent. In smaller powers this improvement will be somewhat less due to the larger proportional effect of turbine leakages, feed pump power and other parasitic losses; and the disadvantages of cost and weight will be relatively greater than on the *Examiner*. As the power of the machinery is increased above that of the *Examiner* the disadvantages of cost and weight will diminish while the advantage of fuel economy will increase. The power at which the adoption of the reheat cycle is warranted will vary with the fuel and machinery prices and with the service of the ship. From present indications the field of application of the high-pressure cycle with gas reheat appears to be in vessels operating normally at 10,000 S.H.P. or higher.

Steam reheat is slightly less efficient than gas reheat, but the machinery will be somewhat simpler and lighter and will therefore cost less. The adoption of the high-pressure cycle with steam reheat may therefore be warranted at powers somewhat lower than with gas reheat.

Experience with the *Examiner* so far has justified the experimental installation and may well lead to the future adoption of the high-pressure reheat cycle for merchant ships. As stated in the original paper, the reheat cycle is not in conflict with the use of higher temperatures; the two sources of gain may be used together.

The builders and operators of the vessel and its machinery have contributed largely to this forward step in geared-turbine propulsion, but the primary credit is obviously due to the Maritime Commission, whose broad vision and progressive policy led to the undertaking.

POWDER METALLURGY: ITS PRODUCTS AND THEIR VARIOUS APPLICATIONS.—The popularity of powder metallurgy depends both upon the possibility of manufacturing metal parts having properties which cannot be achieved in any other fashion, and by the fact that it is frequently more convenient or cheaper to use the technique than other methods of manipulation. A number of examples are cited in which the technique would be of interest in the field of marine engineering. This paper was presented at a meeting of the North-East Coast Institution of Engineers and Shipbuilders on February 19, 1943, by Mr. W. D. Jones, the author.

Powder Metallurgy is the art of making metallic articles or masses by molding powdered metals. It bears some similarity to the methods by which plastics are made. In general, there are three principal possible advantages of the powder-metallurgy technique which are responsible for its growing popularity, namely:

(1) It is frequently possible to manufacture metal parts which have shapes or properties which cannot be achieved in any other fashion. Examples of this technique are the porous bearing, filter, or wick, the bimetal contact material, and the hard metals.

(2) It is often more convenient to use the metal-powder technique than methods of casting. Cases of this technique are the manufacture of tungsten, molybdenum, platinum, the Alnico magnet, and impregnated diamond tools.

(3) It is frequently cheaper to use the powder-metallurgy method, and in many cases is a better all-round manufacturing proposition. Examples of this are the various small iron parts which are now being made in America.

The manufacture of bearings in porous bronze is well established in this country and they are extensively employed in all fields of engineering, particularly in automobiles, aeroplanes, electric clocks, sewing machines, refrigerators, and vacuum cleaners. They excel in circumstances where it would be difficult to lubricate periodically. Their principle is based on hallowed bearing tradition, namely, that a successful bearing alloy must contain a mixture of hard and soft particles. In this case the principle is taken to the logical extreme and the hard particle, or matrix, is a 90/10 bronze, and the soft particle is a hole or pore. The porosity of these bearings normally varies between 25 and 40 per cent by volume and is susceptible of very exact control in manufacture. In many cases the amount of oil which they contain is sufficient to last them for the length of their natural life, although, of course, they can still be fed with oil in the normal way, in which case the pores act as a capillary filter for solid foreign particles. These bearings are particularly economical in oil, and one important advantage which is claimed for them is the fact that a continuous lubricating film always exists over the whole bearing surface even before rotation of the shaft commences. This is an important point if it is true, as is frequently repeated, that the principal wear in heavily loaded conventional bearings takes place during the first few moments of rotation before the oil has formed a continuous interfilm. It is also interesting to note that these porous bearings deliver more oil as they warm up. Mere warming in the hand causes oil to exude from the pores. Porous bronze material of this type has found a variety of applications apart from simple bearings.

The successful manufacture of these bearings is not a simple matter. The process commences with copper and tin powders made to very carefully drawn up specifications. Generally, the particle size is of the order of 200 to 300 mesh and they are mixed together in a 90/10 proportion. Some manufacturers add a small percentage of powdered graphite and others a small percentage of a lubricant to facilitate the pressing operation. Various types of presses are employed. The development of this industry took place using a slow-speed hydraulic press and this type is still employed for the largest sizes of bearings. The normal manufacturing output of today, however, comes from high-speed mechanically operated presses of the type which have been so much employed in the pharmaceutical industry for manufacturing tablets and pills, etc. Such presses are of the eccentric, cam-operated, or rotary type. They have to provide for rapid operation up to 500 pieces per minute, automatic feed of the correct weight of powder, pressing, and automatic ejection. The manufacturers of these types of presses have been very ingenious and successful in devising means of balancing loads and distributing pressures in dies of various complicated shapes. This is a much more difficult proposition with metal powders than is the case with plastics pressing, because metal powders possess little ability to flow under pressure in a die, with the consequence that considerable frictional forces are easily set up. In a pressing of any considerable depth it therefore generally becomes desirable to press from both ends simultaneously and such a procedure is generally followed, combined with a movable core rod in the case of bushing dies.

The compacts on ejection from the press are quite strong enough to handle and must now be heat treated or sintered. The furnaces employed are developments of the usual type of continuous brazing of bright annealing furnace. Different manufacturers employ different designs and sizes, but they all consist essentially of a long narrow straight line muffle furnace in which the compacts are pulled, or pushed, or conveyed, on a travelling mesh belt, or a roller hearth through a heated zone and then through a long cooling zone. A protective atmosphere is maintained in the furnace and it is possible to use atmospheres such as hydrogen or cracked ammonia; it is nevertheless generally considered necessary to turn to a cheaper atmosphere, namely, combusted coal gas. Several companies in the States and in this country manufacture suitable plants in which city gas and air are mixed in the correct proportion and combusted over a catalyst, the water being subsequently condensed. In some cases the gas may be dried completely and purified before passing to the sintering furnace. During the sintering or fritting operation the tin melts and gradually alloys by diffusion with the copper, producing a comparatively strong, but porous mass of bronze.

One of the most important advantages possessed by the powder-metallurgy technique is that articles can be made exactly to size and shape without machining. This means, of course, working to customers' tolerances, but standard stocks of such bearings in the form of plain bushings generally have limits on internal diameter and outer diameter of minus 0.001 inch up to 1½ inches internal diameter, and limits on length of plus or minus 0.005 inch up to 1½ inches length. Closer tolerances are met for special requirements. During the sintering stage dimensional changes occur which may be either a growth or a shrinkage, generally the former, and one of the difficulties in manufacture is the close control of these changes. In practice, it means a very careful control over the quality of the powder, the composition of the mixture used, the pressing operations, and the exact time and temperature cycle in sintering.

After sintering, the bearings are impregnated with lubricating oil either at 110 degrees C. for 10 or 15 minutes soaking, or at lower temperatures in a vacuum chamber. Finally, the bearings are sized to the necessary tolerances

in a mechanically operated sizing press which may be a suitably modified type of the familiar punch press, or merely the original powder press.

On much the same lines porous bronze compacts are being manufactured and sold as filters for various solutions. Bronzes, copper-nickel alloys and pure nickel are being used for this purpose. The porosity varies over a wide range and may reach 80 per cent by volume. They are used not only in the chemical industry but in domestic refrigerators and domestic oil heaters. One filter some 5 inches long and 2 inches in diameter has been developed as the fuel filter in a Diesel engine. Also, much on the same lines, bearings and valve guides are being manufactured out of iron powder and mixtures of iron powder and copper.

Hard Metals.

It may not be realized by most engineers that the familiar hard metal carbide tool of the type of Wimet, Ardoloy, Cutanit, Tecometal, etc., is made entirely by powder metallurgy. It is, in fact, one of the earliest and still the principal example of the technique. The manufacture of these materials is very difficult and complex and every stage has to be accompanied by the most rigid scientific control. It is not possible here to give more than an outline of a typical process. Compositions of these materials vary very considerably, but by far the greater quantity produced consist of tungsten carbide with or without a proportion of titanium carbide together with a proportion of binding or auxiliary metal (generally from 3 to 13 per cent) which is usually cobalt, with or without proportions of nickel or iron. In America, tantalum carbide is being used to a considerable extent. Tungsten carbide can, of course, be melted and cast, even although the melting point approaches 3000 degrees C., but it has been found by experience that a product made in this fashion is perfectly hopeless as a cutting tool. It is intensely hard, of course, but it is also extremely brittle and has no ability to withstand the shocks it will receive in use on a lathe. This is an excellent example of how powder metallurgy comes to the rescue and enables one to combine the hardness of the hard metal particles with the toughness of the bonding metal to produce a tool possessing the optimum qualities of both. It is a product which could not be manufactured in any other manner, and the process is all the more remarkable when one considers that the two substances present will not normally alloy with each other, at least at room temperature.

An outline of the method of manufacture of the simple tungsten carbide tool bonded with cobalt is as follows: First of all the powders must be made. This involves preparation of pure tungsten oxide from the ore and reducing it in stages by heating in hydrogen until a pure tungsten powder of the right grain size distribution and qualities is obtained. The tungsten powder is then mixed with suitable carbon powder and heated in hydrogen in a carbon tube at a temperature approximating 1500 degrees C. This operation can be considered as a sort of case-hardening of the tungsten powder and the product is tungsten-carbide powder, although it is not necessarily pure after the first carburizing operation. Along similar lines, by reduction of the oxide by hydrogen, cobalt powder is made, and again great care has to be taken that a powder having suitable chemical and physical properties is obtained.

Secondly, the two powders are mixed together in the desired proportions and ball-milled together for considerable periods of time to ensure very thorough incorporation of the cobalt with the carbide. Next, the two powders are pressed under hydraulic presses in suitably shaped dies generally arranged to form rectangular bars. A small proportion of paraffin wax dissolved in a suitable solvent is added to the powder before compression.

This considerably aids compaction and produces pressed sticks that are just strong enough to be handled.

The sintering operation is divided into two stages, the pre-sintering and the final sintering; the first stage is conducted in hydrogen in tube furnaces at a temperature of approximately 800 degrees C. In this pre-sintering stage one can regard the change taking place in the material as a sintering of the cobalt only. The product after cooling is then found to be reasonably strong, at least sufficiently strong to permit of its being shaped by cutting with carborundum discs, or by the usual operations of turning, drilling, or filing. In cutting the pre-sintered bars to shape, it is necessary to make careful allowance for the shrinkage that takes place during the final sintering stage, and which may amount to 20 per cent. It is necessary to make this allowance as accurately as possible because, of course, the finished material is much too hard to be sized and any final adjustment in dimensions has to be made by expensive and laborious grinding operations. The final sintering takes place in hydrogen at a temperature of 1400 to 1475 degrees C., depending on the composition. This is a delicate operation requiring great attention to detail. Such a high temperature necessitates the use of special furnaces, and these are generally either carbon tubes heated by the direct passage of current, or alundum tubes wound with tungsten or molybdenum wire maintained in an hydrogen atmosphere. The temperature control of the furnace must be very exact and the hydrogen atmosphere has to be extremely pure and dry. Finally, the sintered tips are brazed to the tool holder and are then ground to size and polished (frequently by the use of a diamond impregnated lapping wheel, which is also a product of powder metallurgy).

Contact Materials.

The modern contact material is a very fine example of powder metallurgy. Successful electrical contact materials are required to possess a formidable range of qualities. They should embody in the one alloy high electrical and thermal conductivity, high melting point, high hardness and wear resistance, low contact resistance, low vapor pressure, resistance to formation of tarnish films, and resistance to welding and formation of pits and beads caused by arcing, or transfer of metal from one contact to the other. There is no known cast metal or alloy which has any pretension of being able to meet all these requirements at one and the same time.

Magnets.

The Alnico magnet is also a very fine example of the modern powder-metallurgy technique. The composition is somewhat variable according to the grade and manufacture, but in general runs 9 to 13 per cent aluminum, 17 to 24 per cent nickel, 5 to 12 per cent cobalt, sometimes copper, and the remainder iron. This composition is a most undesirable material to melt and cast, and the situation is made much worse by the fact that these magnets are frequently required in very small sizes (weighing as little as 0.15 grams) and often in very complicated shapes. Moreover, the alloy has a high melting point in the neighborhood of 1500 degrees C., is very sticky and sluggish when molten, and it is also very difficult to prevent the aluminum from being lost by oxidation. The cast alloy is mechanically weak and easily broken in shaping and, in addition, is far too hard to be shaped otherwise than by grinding. It is not difficult to understand, therefore, that once this magnet material became popular attempts were soon made to manufacture it by the methods of powder metallurgy.

The process of manufacture follows very closely the lines of that used for hard metals, with modifications suited to the special compositions and the

necessity of producing specific magnetic properties. In this manner the powder-metallurgy technique is able to solve a problem which in some cases is acutely difficult to solve with a casting method. Furthermore, additional advantages are claimed for the powder magnet. In the first case, no casting method can approach the degree of accuracy with which the composition can be controlled by powder metallurgy. Secondly, the sintered magnet does not suffer from coarse crystalline growth which renders the cast magnet weak; thirdly, the sintered magnet does not suffer from typical casting defects such as blow holes, cold shuts, cracks, or segregation of impurities to the grain boundaries; and, lastly, the dimensions of small sizes can be very closely controlled and any grinding that may have to be undertaken is very much less than that associated with the cast magnet.

Refractory Metals.

Further examples of circumstances in which it is more convenient or better to use the powder-metallurgy technique than casting, are afforded by the refractory metals such as tungsten, molybdenum, tantalum, platinum, etc. All these materials can be cast, but it is an expensive and difficult technique in view of the high melting points, and in many cases the cast product is certainly not so satisfactory as that made from powders. It is particularly interesting to note that platinum has been worked up by powder metallurgy from the very earliest days and the details of the process were described by Wollaston in 1829.

Tungsten metallurgy is a typical example of powder metallurgy applied to the refractory metals. The tungsten powder having very carefully controlled chemical and physical qualities is reduced from the oxide by heating in hydrogen. The powder is pressed under hydraulic presses into bars from 8 to 24 inches in length and normally 10 by 10 millimeters in cross section. Additions of paraffin to the powder may be made to assist the pressing operation and improve the green strength of the compact. Next, the bar is pre-sintered in hydrogen at 900 to 1100 degrees C., for half-an-hour. This treatment is given purely in order to increase the strength sufficiently to permit the manual handling for the next stage, which is the final sintering operation. This operation is conducted by mounting the bar between water-cooled contacts in an atmosphere of hydrogen, and an alternating current is passed through it sufficient in intensity to raise the temperature nearly to the melting point. A normal bar requires a current of some 2100 amperes at 10 to 15 volts for a period of some 30 minutes. The temperature is controlled by regulation of the wattage employed. During sintering, shrinkage to the extent of some 17 per cent occurs. After sintering, the bar is strong, but very brittle, and cannot be deformed at room temperature, without fracture. It can, however, be manipulated in the neighborhood of 1300 degrees C., and is, in fact, subsequently brought down to the dimensions of a wire by hot swaging at these temperatures. Other complicated mechanical and thermal processes follow to produce the remarkable single crystal "coiled-coil" filament which is so familiar.

General experience gained with powder metallurgy, and in particular with the refractory metals, has shown that it is a technique which is particularly suitable for the working up and consolidating of metals in mass (as distinct from the manufacture of articles). Over the normal processes of smelting and casting, powder metallurgy shows several advantages; in particular it is possible to control compositions with precision, it frequently permits the production of purer metals, it obviates casting defects such as blow-holes, inclusions, etc., it allows control over grain size and shape which cannot be approached by casting, and last, but not least, frequently introduces a considerable saving in power and labor expenditure. These advantages are

familiar to the workers in refractory metals, but are only just beginning to be appreciated by the metallurgist handling the everyday metals, iron, nickel, copper, etc. It is an interesting speculation whether the metallurgy of the commoner metals will become powder metallurgy. There are indications that this is taking place and one recent example is the coalescence process for copper, which is no more than a method of extraction metallurgy for extracting and working copper from its ores; but it is powder metallurgy pure and simple, and inasmuch as the product appears to have improved qualities with respect to electrical conductivity, ability to absorb cold work, and freedom from casting defects, it is a technique which is likely to develop and extend in the future.

Consideration will next be given to the field of powder metallurgy where, apart from other reasons and advantages, it is actually a cheaper technique than most methods. This field is best illustrated by the manufacture of a number of various small iron parts which is being undertaken on a considerable scale in America.

Iron Parts.

Saving in manufacturing costs by using powder metallurgy is mainly achieved at the present time in cases where the die costs and the metal-powder costs can be more than offset by the production of large numbers of parts in which, normally, a considerable amount of skilled machining is required. The iron parts referred to are more or less non-porous, or have a low porosity, and are not to be considered as bearing materials, although they are frequently given self-lubricating properties by oil impregnation or addition of graphite. Typical of such parts are a tappet from a washing machine, a part from a push-button radio tuner, a part in a dictating machine, a non-squeaking part from an automobile window winder, and an automobile oil-pump gear wheel. This last item is a remarkable achievement and has received considerable publicity. It is a small gear used to circulate the oil in a General Motors car. The gear teeth must be true involute curves and accurately formed to avoid noisy operation or binding. In the past it has been machined from a cast blank at considerable expense. The powder-metallurgy product is in every way superior and cheaper. A large number of advantages have been cited in its favor, but it will suffice to mention the facts that machining costs are avoided, waste of raw material avoided, and that the gear has a more accurate contour and better surface finish and is therefore more silent in operation. Iron parts of this type are manufactured much on the same lines used for the porous bronze bearings. Similar presses can be used, but the pressures are higher, from 30 to 40 tons per square inch. Sintering furnaces are similar, and the sintering temperature is in the region of 1100 degrees C. Furnaces fitted with roller hearths, or wire mesh conveyor belts, are employed. The sintering time is from 20 to 40 minutes in an atmosphere of dried partially combusted hydrocarbon gas. There is, generally, a slight shrinkage during sintering amounting to ½ to 3 per cent. In most cases the pieces are sized after sintering, generally cold, but in some cases hot, at 400 to 500 degrees C. Iron parts made in this manner have been produced experimentally with tensile strengths exceeding 50 tons per square inch, but with the qualities of iron powder at present commercially available, and bearing in mind that wear on dies increases with pressing pressure, it is not customary to exceed a tensile strength of 9 to 15 tons. These parts can, therefore, be regarded as having very similar properties to the ordinary cast-iron. As commercial experience is gained it will become possible to make use of the results of laboratory investigations where higher pressures and alloy-steel powders have been employed.

Hot Pressing.

Finally, something must be said about hot pressing as a powder-metallurgy technique. In this method of molding powders, pressure is given to the powder while it is cold, and the cold compressed compact is heated up and then pressed again while it is hot. There are a variety of methods by which the method can be worked out, and similar techniques involve hot forging or hot extrusion. The method is not a difficult one, but so far has received little or no industrial attention. I have examined a wide variety of alloys prepared from powders by this technique, and find that it not only combines all the advantages usually associated with powder metallurgy but in addition is capable of giving compacts having very excellent mechanical properties, and in some cases superior properties, to the cast article. These results have been published in detail, and it will be sufficient to state here that with an ordinary cast-iron, tensile strengths of 36 tons square inch have been obtained, and with bronzes, tensiles in excess of 23 tons square inch combined with an elongation in excess of 75 per cent. Similar results are obtainable with brasses and various other copper base and complex alloys.

Recently, an account has been published describing the application of hot pressing to the manufacture of steel parts from steel turnings. The process has been worked out in a very simple manner and appears to be highly successful. Starting with steel turnings valued at little over ½ cent per pound, a part is produced without machining in six operations, which has approximately three times the strength of cast-iron. The part concerned is a bearing lock sleeve used to hold the roller bearing in the differential carrier of the Chevrolet car. It is about 3 inches in diameter, 5/8 inch thick, and a section thickness of 3/8 inch. One face is smooth at an angle of 20 degrees, and the other with concentric recesses near the inner and outer edges. It weighs 8 ounces and hitherto was machined from grey cast-iron.

The powder-metallurgy method is as follows: Steel chips and turnings are fed into swing-hammer crushers which reduce them to a very coarse powder. They are then compacted in a hydraulic press under some 30 tons per square inch. The parts are then treated in a pusher type sintering furnace fed with combusted gas. The furnace handles six parallel tracks of parts at a rate of 500 pieces per hour, giving each part approximately 15 minutes treatment at a maximum temperature of approximately 1050 degrees C. As the pieces drop from the sintering furnace they are quickly transferred by hand to the hot press. The dies used are of the hinged type and water cooled with a series of eight jaws applying pressure uniformly around the outer edge of the washer, while upper and lower dies compress the surface. Pieces are handled at the rate of 12 per minute in this press and are automatically removed from the dies and slide down a shute into a water-quenching bath. When cool, the part goes to a trimming press and is then finally sized.

General Possibilities.

Anyone who studies this process, and some of the others already described, cannot fail to be impressed with the fact that under favorable circumstances the technique of powder metallurgy permits either a saving in labor or a transference from skilled labor to semi-skilled labor, and also either a saving in raw material (by reducing losses) or a transference from virgin metals to the practical use of secondary metals. If this is appreciated, it will be realized that the processes of powder metallurgy are particularly suited to war-time production conditions. An extensive adoption of this technique would release considerable skilled labor and prevent the

wastage of much raw material. While the possibilities of powder metallurgy are generally appreciated for the production of materials having special qualities, such as contacts, porous bronze, etc., it is only just beginning to be appreciated by engineers that the powder-metallurgy industry is now at a stage where it has begun to manufacture articles that can be, and have been, manufactured by other methods, and that the powder-metallurgy technique is now a preferred technique for the production of numerous machine parts characterized by excellent physical properties, accuracy of configuration, and substantial lack of porosity. In iron articles, tensile strength up to 25 tons square inch present no difficulty in production, brasses and bronzes may be obtained with tensiles between 15 and 25 tons square inch accompanied by elongations between 20 and 75 per cent. Little work has been done on aluminum alloys, but physical properties similar to castings have been obtained. These results in the broad field of small non-porous precision machine parts are accompanied by the advantages of rapid production (300 parts per minute from one press) high dimensional accuracy (tolerances of $\pm$ 0.001 inch on 2 inches) and little or no scrap loss. In America, production of such articles is being undertaken in various metals to a considerable extent and may develop into an industry rivalling that of the plastics. Production work of this kind is not yet being undertaken in this country, although there are a number of firms investigating the position. As an example of the possibilities of powder metallurgy, the following represent a list of articles which are, or could be, made from powders in the field of marine engineering. This is not an exhaustive list, but represents a few items which come to the mind as being typical examples.

Piston rings, either in special alloys or not, for feed pumps, Diesel engines and reciprocating steam engines. Also packing rings and the like.

Valves and seatings such as for feed pumps, safety valves, steam traps, etc.

Turbine blades.

Bushings and bearings for light auxiliary machinery, small cams, tappets and pinions.

The electrical field embraces many possibilities, such as commutator segments, brushes, contacts, etc., but the largest field is possibly in the manufacture of instruments where numerous small parts are required, cams, tappets, screws, bearings, magnets, etc. The radio and telephone trades already employ considerable amounts of powders in the manufacture of cores and transformers.

SAMPLING AND QUALITY CONTROL.—This is an abstract of an address given by Dr. W. Edwards Deming, of the Bureau of the Census and Bureau of the Budget, at a joint session of the Institute of Mathematical Statistics and the American Mathematical Society, Vassar College, on September 9, 1942. Dr. Deming's address was published in the March 5, 1943, issue of Science.

The control chart was devised by Shewhart in 1924 to help disclose the presence of extraneous causes of variability that are worth looking for; also to give greater quality assurance in devising acceptance procedures.

Two problems confront the manufacturer and the statistician in industry:

Problem A: What to do with this lot? (Accept it, reject, pass, scrap, rework, or regrade it.)

Problem B: What to do with the process? (Leave it alone; or look for some identifiable cause, make some adjustment, use different raw materials.)

The quality control engineer does his best work in either problem when he recognizes the existence of both, and deals with both simultaneously. In

particular, the decision whether to accept or reject a lot of manufactured articles can not be dissociated from the question of control: is this lot one of a series of lots that were made in a state of statistical control? If the answer is no, each lot must be examined in considerable detail if its quality (average diameter or per cent defective) is to be determined accurately. If the answer is yes, and if the lots are large, inspection of a small percentage of each lot, or of every k-th lot, will give the needed quality assurance. This *increased quality assurance* with *decreased inspection* is one of the advantages of the Shewhart methods.

The Shewhart methods are equally important in the social sciences, where a similar division of problems exists, though with some necessary modifications. With the increasing number of surveys of local and national scope being carried out to supply data on the social and economic states of the population, and on natural resources and stocks, and with the ever-increasing need for accuracy in predictions, the requirements being placed on sampling methods and the interpretation of data are assuming increased severity.

Statisticians and mathematicians are rendering meritorious service in these critical times. I shall try to show you how they can render still more.

Variations in Nature.

He who ignores the inherent variability of all nature does not understand nature. You may leave home at the same minute morning after morning, but you do not always arrive at your office at the same time. The peas in a pod are not alike, but they are usually alike enough for the purpose. Two telephones are not alike, but the variations are within limits that are known to be close enough and known in advance of production. Traffic accidents, deplorable though they are, do happen, and what is more, *will fluctuate week by week,* even under a constant set of causes. Likewise, a sentence will have various meanings, depending on who reads it. The meaning of anything that you say is the *action that it produces.* In attempting to write clearly you can only hope to narrow the spread of the interpretations—*i.e.,* of the actions or emotions that your writing gives rise to when readers read it.

I heard that the president of one large corporation was always anxious whenever the amount of scrap was greater one day than it was the day before. Now of course it is well to get interested in scrap, and the control of scrap incidentally offers one of the best uses of the Shewhart control chart; but if one looks for trouble in the plant every time the amount of scrap is higher one day than it was the day before, he will be looking for trouble far too often. It costs money to look for trouble. The amount of scrap is going to vary day after day even under controlled circumstances.

Definition of a Constant Cause System.

A constant cause system may be described as one that produces numerical results that vary from one to another like a sequence of numbers that are drawn from a bowl of physically similar numbered chips, blindfolded, and with replacement and shuffling. Drawing from a bowl is the limiting attainable state of knowledge, which is to say, this is the limiting attainable state of stability.

The prime requirement of a constant cause system is stability, and hence the predictability of future percentiles or probability tolerances. It is important to recognize that a constant cause system does not produce constant results.

Randomness, Statistical Control and Technical Control.

Any observation, measurement, or table of frequencies, comes about as the result of applying an operation. Whatever the operation, a repeated appli-

cation thereof gives a new observation. Continued repetition gives a sequence of terms—a *population* of results. Thus, suppose an article is being manufactured, one after another, and let each be measured for its outside diameter. The situation is something like this—

$$\text{Article: } F_1, F_2, F_3, \ldots, F_n$$
$$\text{Diameter: } X_1, X_2, X_3, \ldots, X_n$$

The manufacture and the testing and the recording of the diameters constitute the operation of obtaining the n values of X.

In the state of randomness or stability, the terms of the sequence behave as if they were being produced by a constant cause system—they behave as if they were being drawn from the bowl. Without stability, probability tolerances for future terms can not be set purely on the basis of past terms.

The attainment of randomness is much more difficult than is commonly supposed. It may require months. Statistical control is more than technical control. In the latter, the terms of the sequence are merely kept within certain bounds. Be they ever so narrow, this is not statistical control. Of course, technical control comes first, and is often sufficient.

A practical criterion of stability is the Shewhart criterion. If 25 or more successive points, each consisting of four consecutive terms of a sequence, fall within the control limits, after it is thought that all possible sources of extraneous variability have been eliminated from the process that gives rise to the sequence, and if no trends or patterns are exhibited by the sequence, it is possible to set probability tolerances on future terms of the sequence, and thus to predict how much of tomorrow's product will fall within various limits—possible in the sense that experience, in many different kinds of production, covering many years, has borne out the advisability of so doing. I shall return to this topic later.

The Fundamental Problem of Mathematical Statistics.

The fundamental problem of mathematical statistics is to set "probability tolerances," *i.e.*, to set limits within which 99 or some other per cent of the next (*e.g.*) 1000 or 10,000 terms of a random sequence will fall. For instance, on the basis of the past n diameters in the example cited above, the problem is to say what proportion of the next 1000 or 10,000 diameters will fall within the limits X_1 and X_2. Failure of the putative percentage of terms to fall within these limits may be taken to indicate the presence of an "extraneous cause"—a cause not associated with the constant cause system identifying the random operation by which the past n terms of the sequence were generated.

The need for predictions in the form of probability tolerances as a basis for action is recognized much wider than it was a few years ago. Examples of action that are supposedly based on probability tolerances can be drawn from almost every field of scientific endeavor. For instance, no measurement, no survey, would be considered worth publishing unless there is evidence that repetitions would duplicate it within stated limits. Take government planning based on census returns; action can be based on the returns only if the census (whether by complete count or by sample) is carried out in such manner that repetitions of the survey, on or near the census date, would result in tables close enough to those that are actually published by the Census—*i.e.*, close enough for the purpose intended. The standardization of a drug is a problem in probability tolerances; dosage (future action) is based on the potency of the drug as determined by experiments which are carried out to make it possible to state in advance the limits within which 95 or 99 per cent of the next 1000 or 10,000 tests (results of doses)

will fall. Recommendations regarding the planting of next year's crops should be based on predictions in the nature of probability tolerances for future yields, in terms of certain operations (variety, treatment, fertilizer). The prediction of ability for the selection of personnel calls for probability tolerances.

When probability tolerances for future terms of a random sequence are to be set on the basis of past terms alone, mathematical statistics is involved in the pure state—a problem of Type A as I have elsewhere classified the problems of statistical inference. When the sequence is not random, the problem is not entirely mathematical, and may even be hardly at all mathematical; recourse must then be had to whatever knowledge there is concerning the underlying causes that make the terms of the sequence behave as they do. The problem is then one of Type B. The problem is partly or mostly Type B when there are not enough terms in the past, even though they are random, to allow probability tolerances to be set close enough for the purpose by mathematics alone. Often there is only one term, one result, one experiment; the rest is knowledge of the subject-matter.

The Shewhart Control Limits Are Action Limits; They Strike An Economic Balance Between Two Kinds of Errors

Brifly, the Shewhart methods consist of studying a sufficiently large quantity of data, not as a single sample, but in a sequence of rational subseries that are obtained by breaking up the data in a manner that will indicate with a minimum amount of data the presence of extraneous causes, and the existence of stability when stability exists between the subseries. The most useful way of breaking up the data into subseries must be determined in each problem by knowledge of the subject-matter, but there are some guiding principles to keep in mind. It is important to collect the data and plot the points without delay, in order that action can be taken in time to ward off trends that are not wanted.

The presence of extraneous causes worth looking for is indicated by failure of a point on the control chart to fall within the "control limits." The problem of setting probability tolerances and control limits is a problem in action: What to do? to look or not to look for an extraneous cause? There must be an economic balance struck between the two kinds of errors—looking for trouble that does not exist, and failing to look for trouble that does exist.

There is not time here to tell you how to go about calculating and plotting a control chart and how to draw the control limits. Fortunately, with the publication of the American War Standards, and Colonel Simon's book,* it is possible now to point to a pretty full account of the steps in application.

Diagram of the Statistical Study of Causes.

The practicing statistician welcomes all the distribution theory that has been developed to date. Far from there being too much mathematical statistics, even in the state of randomness there is not enough!

Mathematicians have too often assumed that it is easy to produce random variates. It is easy to assume that, and the problems are interesting. Of course, not everything is or should be useful, and we should be thankful for that, but the usefulness of much mathematical work in statistics has often been greatly overestimated because randomness is presupposed, with no indication given to show how far the calculations are invalidated by lack of randomness and what to do in the absence thereof.

* Col. Leslie E. Simon, "An Engineers' Manual of Statistical Methods," John Wiley, 1941.

Urgent requirements of government and industry now challenge the best mathematical talents in the country. In spite of the volumes of texts and periodicals that have appeared in the statistical field, there are parts of the subject yet untouched—one could almost say yet unrecognized. The need is urgent: the opportunity is great. New tools, new channels of thought are being called for.

Other Future Requirements.

In the future there will be increased attention to the operational point of view, by which I mean that statements made by statisticians will of necessity be confined more and more to statements that theoretically at least can be subjected to test, because their statements will be tested.

Theoretical statisticians have too often evaluated the methods of quality control in terms of their own theories, without stopping to acquire an appreciation of the problems that face the practicing statistician, who must stand by and see his predictions put to a test. For instance, I have seen it argued (innocently enough) that people in quality control ought to use the nomenclature and language of the theory of estimation.

There will be increased attention to the distinction between chance as defined *a priori* as a basis for theoretical calculations in probabilities, and the meaning of the word chance when it is used to designate relative frequencies predicted to fall within certain limits in a controlled experiment. Calculated chances are one thing, but actual observed frequencies, even under a constant cause system, may be another. In other words, it is necessary to recognize the distinction between what is in the bowl, as determined by some standard method of examining part or all of the chips, and what we get by performing some other operation on it. One can not set probability tolerances regarding the results of drawing from the bowl, purely from knowledge of what is in the bowl as determined by some standard method.

For example, the phenomenon of the undercount of children under 5 is well known among sociologists. Whether the census is taken by complete count or by sampling, the undercount of young children makes its appearance. How do we know? In the same manner in which it was discovered many years ago. In the census 10 years hence, with allowances for deaths, and for in and out migration, there will be more children of age 10-15 in any sizable area than there were children of age 0-5 ten years before. The phenomenon invariably repeats itself, in this country and elsewhere. People just will forget the baby when the Census man comes!

In this illustration, the count 10 years hence is the "standard measurement." The census method of counting the children of age 0-5 at the date of the first census is the other operation. If it were repeated at small intervals of time, it would perhaps show statistical control. Suppose it does: neither the average result nor the probability tolerances for this "other" operation can be determined *a priori* by the standard count. Likewise the converse: it is too much to hope that the standard count could be determined by the average result or the probability tolerances for the census operation of counting children of age 0-5.

Some Remarks on the Practice of Statistics.

Faced with realities, it is sometimes difficult for the practicing statistician to frame his problems in the language of the theoretical statistics that has so far been developed. The problem of attaining control, for example, is not analysis of variance, is not a test of significance, is more than a problem in probabilities, and more than a problem in the statistical testing of hypotheses in the usual sense. It is a problem in *action*. The control limits must provide an answer to the question: What to do? Shall we or shall we

not look for trouble? An economic balance must be struck between two kinds of errors. The question is not whether an extraneous cause is operating to make a point plotted from inspection data fall where it does (inside or outside the control limits): the question really is *whether it pays to look* for an extraneous cause.

What Can Be Done?

Now is the time to do something. Statisticians have a great deal to offer. Let them bring it forth. The following 7-point plan is offered as a starting point, to be replaced by better suggestions as experience develops.

I. *Intensive courses in quality control.*—By intensive I mean intensive, covering 7, 8, or 10 days, including Sundays, 8 hours per day. Stanford University gave such a course in July, and another in September. Thirty-two picked delegates from industry attended in July, and 31 in September. Most of them were well advanced in their organizations, with authority to try out statistical methods, and they went home with the ability to do so. The 80 hours' instruction was sufficient to give them an excellent start. All phases of the subject were taught, including diagnosis of data brought to the conference, and arrangements for continuation study afterward. The instructional staff at Stanford was supplemented by practical men from government and industry—a vital necessity in such undertakings.

A semester course in quality control is good so far as it goes, but it is not sufficient for the present needs. It is too slow, and the yield too low. The important thing is to give intensive courses to men in industry, now, patterned after the ones at Stanford.

With the close relation between price control and quality control, and the necessity for quality determination and the standardization of textiles, foods, drugs and hospital supplies, the need for expert statistical work in this line is multiplied manyfold under present conditions.

II. *Intensive courses in other fields.*—Fields other than quality control could be covered by intensive courses for the benefit of men in government and industry. For example, something could be done in the way of teaching statistical methods in psychological tests for placement of personnel.

III. *Modification of instruction in regular courses.*—In regular courses of instruction, students have often been given an incomplete picture of the problems of mathematical statistics. The result has been over-confidence in his ability, nonsense calculations and outright mistakes that might be serious if not caught, with consequent mistrust of statisticians. This will always be true, but the teaching of general principles has not been broad enough, and what is worse, the student has not been advised and warned of his deficiencies.

IV. *Short monographs on various statistical procedures.*—All over the country I have found men in industry, in government and in research organizations eager to learn the tools that the statisticians have developed. From everywhere comes the question: "Where can I learn more about this? Is there anything printed in simple language that I can understand?"

Here again, something can be done, and is being done. I can refer you, for instance, to the American War Standards in the field of quality control. With remarkable foresight, perceiving the coming need for statistical methods in war industries and ordnance inspection, the War Department in December, 1940, asked the American Standards Association to develop concise treatments for the application of statistical methods, for use both in acceptance inspection, and during manufacture. A committee was appointed, with

the result that two standards appeared in May, 1941, and a third in July, 1942, with titles as shown below: *

1. Guide for Quality Control, 1941.
2. Control Chart Method of Analyzing Data, 1941.
(Nos. 1 and 2 are bound together and sell at 75c.)
3. Control Chart Method of Controlling Quality During Production, 1942: 75c.

These serve as guides in application and for introductions to texts and other books on the subject, and they contain references to texts and monographs on the subject for further study. Similar brochures on procedure could be produced for other statistical techniques.

V. *References to current articles and books in various fields.*—The Institute of Mathematical Statistics and the American Statistical Association could perform a valuable service by running in each issue of their journals a list of references to current articles and books on applied statistics, broken down into various fields—sampling in social and economic surveys, quality control, psychological tests, presentation of data, and other subjects.

VI. *Exposition of methods in published articles.*—In both journals, there could be more serious attempts to show the reader how to apply the methods that are presented. No matter how theoretical an article may be, it should nevertheless describe how its contents affect present practices. It should contain directions for application, plainly marked, "Step 1, Step 2, do this, do that, . . ." The hypotheses and conclusions and logic should be described in non-mathematical terms, as well as by strict mathematics.

VII. *Expert assistance.*—The fact is that there are not enough good men in applied statistics nor in mathematical statistics. Right now, all over the country, there are young men grasping, groping, struggling with statistical problems on which action will be taken on a deadline. To whom can they look for assistance? If it could be made known, and if we were prepared, the association and the institute could assist by acting as a clearing house for statistical questions, by referring them to the right man, or by sending the names of experts who can and will go outside of Washington, New York, Chicago, and a few other places, and get their hands dirty.

* Published by the American Standards Association, 29 W. 39th Street, New York.

BOOK REVIEWS.

MARINE ELECTRIC POWER—SECOND EDITION. By Captain Q. B. Newman, Engineer-in-Chief, Retired, United States Coast Guard. Simmons Boardman Publishing Corporation, 30 Church St., New York, N. Y. Price, $2.50.

The second edition of this book has been improved by the addition of six chapters, including chapters on:

Three-Wire Generator.
Direct-Current Generator in Parallel.
Construction of Electric Machinery.
Care and Repair.

For one not well grounded in physics and mathematics or for one who is so grounded, but wishes to review the theory of electric power in its marine application, the book is recommended. The many diagrams and clear and easily understandable phraseology make its reading a pleasure and not a chore. The book can be used for leisure reading to refresh a more scientific knowledge or to obtain clear basic ideas of "why".

MARINE ENGINEERING. By Lieut. Commander J. M. Labberton, U.S.N.R., Published by McGraw Hill Book Company, Inc.

A painstakingly and thoroughly prepared single volume of 434 pages covering the subject of Marine Engineering. Most of the material in the book has been used by the author in lectures on the subject in the Graduate Division of the College of Engineering of New York University. A list of Chapters indicates the scope of the book:

I Hull Design and Resistance.
II Propellors.
III Propulsion Shafting.
IV Reduction Gears.
V Marine Fuels and Combustion.
VI Boilers or Steam Generators.
VII Turbines.
VIII Marine Pumps.
IX Heat Exchangers.
X Forced Draft and Duct Work.
XI Marine Electrical Engineering.
XII Refrigeration.
XIII Feed System.
XIV Heat Balance.
XV Diesel Ship.
XVI Layout.
XVII Astern Operation.
XVIII Electric Drive.
XIX Naval Vessels.
XX Ships' Trials.

In each chapter the subject is presented with no excess verbiage. Each sentence contributes its full share. Perhaps this is why so much is packed into a relatively small volume considering the wide field covered. The book is recommended to either a student or to a practicing engineer as a complete education or a thorough review.

OTHER BOOKS RECEIVED.

THE LUFTWAFFE, ITS RISE AND FALL. By Hauptman Hermann. Published by G. P. Putnam's Sons, New York. Price, $3.00.

ISLANDS OF THE PACIFIC. By Hawthorne Daniel. Published by G. P. Putnam's Sons, New York. Price, $2.50.

JEEPS AND JESTS. By Bruce Bairnsfather. Published by G. P. Putnam's Sons, New York. Price, $2.00.

ON YOUR OWN. By Samuel A. Graham and Earl C. O'Roke. Published by the University of Minnesota Press. Price, $2.00.

AIR POWER AND TOTAL WAR. By Cg.. Caldwell. Published by Coward-McCann, Inc., 2 West 45th St., New York City. Price, $2.50.

QUESTIONS AND ANSWERS FOR MARINE ENGINEERS. Book VII—Diesel Engines—Electrical Equipment. Book III—Material and Calculations—Handy Tables. Compiled by Captain H. C. Dinger, U.S.N. (Ret.). Published by Simmons Boardman Publishing Corp., New York. Price, $1.00 Each Volume.

These are two additional volumes to the series which has been mentioned heretofore in this column. They are small paper covered books presenting questions and answers on the subject, primarily for operating personnel.

PERCENTAGE AND CONVENTIONAL STRESS-STRAIN DIAGRAMS COMPARED.

Iowa Engineering Experiment Station Bulletin 159.

In an effort to extend the usefulness and significance of the stress-strain diagram, and to make it an instrument for a broader understanding of the processes of break-down in engineering materials under static loading, H. J. Gilkey and Glenn Murphy, Research Professors of Theoretical and Applied Mechanics, report the results of a number of years of study and research in Bulleting 159 of the Iowa Engineering Experiment Station, "The Percentage Stress-Strain Diagram as an Index to the Comparative Behavior of Materials Under Load."

As a running log of a test the stress-strain diagram inherently supplies both a quantitative and a qualitative record of the response of a specimen to load. Stress-strain diagrams have been used almost exclusively for evaluating quantitative constants used

in design, but rarely for their qualitative indications, as evidenced by their shape, or as a basis for possible study of the phenomena of failure.

In this bulletin, Gilkey and Murphy present a percentage technique which offers a simple means for study and comparisons of shapes of stress-strain diagrams regardless of quantitative differences. The bulletin supplies illustrative comparisons quantitatively, through the conventional diagram, and qualitatively, through the percentage diagram, for the stress-strain behavior of steel and steel alloys, nonferrous metals, timber, portland cement, plaster of Paris, concrete and stone.

The use of percentage diagrams to compare the behavior of materials in tension, compression, flexure and torsion, and to compare lateral and longitudinal stress-strain behavior is illustrated.

The authors believe that the percentage technique which they have outlined and illustrated can be made to serve a useful and needed function in analyzing the break-down process, thus contributing to the more intelligent use of engineering materials.

Single copies of this 44-page bulletin may be obtained without charge from the Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa.

ASSOCIATION NOTES.

SOME PROBLEMS IN WHICH THE ARMY IS INTERESTED.

The National Inventors Council has secured the consent of the Army to the release of a list of some of the problems in which the Army is interested. A practical and effective solution of any of them will be a real contribution to the war effort. Actual war experience has shown the need of various devices or methods not practically available, and has also shown the need or the desirability of substitutes or alternatives for devices and methods which are already in our possession.

While information of the needs of the Army has only been given to agencies officially authorized to receive and use it, such a list has not heretofore been released since it might give information of what we possess or do not possess. The present list is not of this character and is being released to appropriate professional societies and research organizations in order that it may be passed along to their membership. Additional lists may be released in the future.

Suggestions on any of these problems should be submitted to the National Inventors Council, Room 1313, Commerce Building, Washington, D. C., and should comprise a clear description of the proposal with such sketches or drawings as may be necessary.

1. A method of removing the tetraethyl lead from leaded gasoline to make it usable in stoves, lanterns and small engines.

2. An inexpensive metal suitable for Quartermaster tableware; one having requisite strength, freedom from corrosion by food acids or alkalis; durability and attractiveness.

3. Suitable substitute for rubber for insulating wire; should be flexible and durable.

4. Detectors of enemy personnel who may be approaching (unseen) on jungle trails or fences or similar barriers.

5. Sonic or supersonic means or methods of signalling in the field.

6. Improved means or methods of signalling the identification of ground troops to friendly airplanes and vice versa.

7. Improved traction devices for wheeled vehicles of all types. *Note*: Present chains and other devices are cumbersome, inconvenient to apply and remove and lack sufficient traction.

8. Tracks for tractors and other motorized equipment which will operate efficiently in snow and extreme cold.

9. Better air cleaners for use on tank engines and the like; more effective than present cleaners and requiring less maintenance.

10. Methods of quick-action waterproofing for enabling vehicles to ford water several feet deep, without stalling engines.

11. Storage battery not adversely affected by very low temperatures.

12. The detector and method of locating non-metallic land mines.

13. Equipment or methods for removing land mines rapidly from mine fields without injury to equipment or personnel.

14. Methods of rust-proofing ferrous metals, which are more durable than present methods, such as bonderizing, etc.

15. Absorbents for carbon monoxide or catalysts or other means for oxidation of this gas to render it non-injurious to personnel.

16. Means of defeating darkness to permit vision at night without aid of visible reflected light. *Note:* Probably involves an apparatus to translate infra red rays to visible light.

17. Means of long distance communication outside the present scope of radio and not restricted by line-of-sight projection.

18. Searchlights which may afford ready means for spreading the beam from narrow high intensity to 15 degrees of greatest intensity practicable.

19. A simple non-toxic process for darkening aluminum and other metals; to make them non-reflectant to light.

20. Methods of sabotage by friendly inhabitants within occupied areas.

MEMBERSHIP.

The following have been received into the Society since the publication of the May, 1943, JOURNAL:

NAVAL.

Algea, Bradly C., Jr., Lieut., U.S.N.R., Asso. Principal Inspector of Engineering Material, Inspector of Naval Material, Bethlehem, Pa. Mail, 29 Weldy Ave., Oreland, Montgomery County, Pa.

Arnold, Richard M., Lieutenant, U.S.C.G.

Avila, Frank W., Lieutenant, U.S.N.R.

Ayers, Benjamin K., Jr., Lieutenant, U.S.N.R.

Barnes, Arthur W., Lieutenant, U.S.N.R.

Bethea, James S., Lieut. Commander, U.S.N.

Broms, Leonard Carl, Lieutenant, U.S.N.R., 4658 Atoll Ave., Van Nuys, Calif.

Clements, Roger William, Ensign, U.S.N.R.

Cunniff, J. F., Lieut. Commander (CEC), U.S.N.R., 78th Naval Construction Battalion, ABD, Port Huenema, Calif.

Doty, Arthur Francis, Machinist, U.S.N.

Dow, Chester A., Jr., Lieutenant, U.S.N.

Flinn, A. C., Lieut. Commander, U.S.N.R.

Halota, John R., Ensign, U.S.N.R., Asst. Supervisor of Shipbuilding, Savannah Machine and Foundry Co., P. O. Box 590, Savannah, Ga. Mail, 2820 39th St., N. W., Washington, D. C.

Henning, Howard G., Lieutenant, U.S.N.R., 63 Goffe Terrace, New Haven, Conn.

Hoffer, Clarence W., Lieut. Commander, U.S.N.R. Chief, Mining Section, Materials Division, Production Branch, O. P. & M., Navy Dept. Mail, 532 20th St., N. W., Washington, D. C.

Laney, Robert V., Lieutenant, U.S.N.R., 3 Concord Ave., Cambridge, Mass.

Larrain, Alberto, Lieutenant, U.S.N.R.

Lewis, M. J., Machinist, U.S.N.R.

Newman, Peter, Lieut. Commander, U.S.N.R.

Novak, Edward, Lieutenant, U.S.N.R. Richard's Grove Road, Quaker Hill, Conn.

Perkins, Allen L., Ensign, U.S.N.R., Office of Inspector of Machinery, U.S.N., Electro-Motive Division, G.M.C., LaGrange, Ill.

Phelps, Henry G., Ensign, U.S.N.R.

Roddis, Louis H., Jr., Lieutenant, U.S.N., 52 Massachusetts Ave., Cambridge, Mass.

Ross, Theodore H., Lieut. Commander, U.S.N.R., care Supervisor of Shipbuilding, U.S.N., Erie Concrete & Steel Supply Co., Erie, Pa.

Shields, Santos Vincent, Ensign, U.S.N.R.

Summerell, J. J., Lieutenant, U.S.N.R.

Sweek, Robert F., Lieutenant, U.S.N.

Thompson, DeWitte Lee, Lieutenant, U.S.N., R. F. D. No. 1, Box 100, Haw River, N. C.

Turner, Clifford H. V., Ensign, U.S.N.R., 4643 Somerset Ave., Detroit, Mich.

Civil.

Carroll, Joseph L., Chief Draftsman, Alabama Dry Dock and Shipbuilding Co. Mail, 201 Mohawk St., Mobile, Ala.

Lahecka, Frank H., Sales Engineer, Carnegie-Illinois Steel Corporation. Mail, 130 Prospect St., East Orange, N. J.

Milbury, Charles Ellis, General Superintendent, General Engineering, Inc., Philadelphia, Pa. Mail, Apt. C64, Haddon & Zane Aves., Collingswood, N. J.

Panter, O. W., Chief Engineer, Manager, Martinsen Shipyards, Inc., Seattle, Wash. Mail, 4519 Pacific Ave., Tacoma, Wash.

Tobey, Harold E., Naval Architect, Bureau of Ships. Mail, 1609 19th St., N. W., Washington, D. C.

Associate.

Berky, Stephen T., Marine Engineer, Office of Supervisor of Engineering, San Pedro, Calif. Mail, 4316 Elko St., Long Beach, Calif.

Henke, Lawrence G., Asst. Mech. Engineer, Puget Sound Navy Yard. Mail, Apt. 236, 2006 Parkside Drive, East Bremerton, Wash.

Kain, Ed L., Jr., Engineering Estimator, 206 Engineering Dept., Consolidated Steel Corporation, S. B. Div., Orange, Texas.

Morris, Wilson G., Ordnance Dept., Tacoma Shipbuilding Co. Mail, 4127 Phinney St., Seattle, Wash.

Preston, Irving S., Steel Requirements Engineer, U. S. Steel Corporation, Pittsburgh, Pa. Mail, 4712 Doyle Road, Pittsburgh 10, Pa.

neering
Texas.
ng Co.

Steel
sburgh